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SUBJECT INDEX (C) FUEL FUEL SYSTEM FIRE PROTECTION

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I. ABSTRACT

The testing of gelled fuel's compatibility with a commercial transport fuel system is discussed. The effect upon the strength of kerosene gelled fuels of varying the amount of gelling agent, gel water content, gelation temperature, gel temperature, pumping with different types of pumps, and subjection to a typical vibration spectrum was investigated. The corrosion characteristics of the gelled fuel and the gelled fuel's ability to support microbiological growths was studied. The gelled fuel was also tested for its ability to be pumped out of a section of a 727 wing fuel tank.

II. SUMMARY

In some airplane accidents, post crash fires have claimed lives of passengers that otherwise might have survived. With this in mind, gelled or emulsified fuels have been proposed so that post crash fire could be avoided or postponed, and safe evacuation be facilitated.

The FAA and the U.S. Army both have programs aimed at defining the safety advantage of stiffened fuels over conventional ones in reducing post crash fires. These agencies have also funded testing by various aircraft engine manufacturers to determine the compatibility of stiffened fuels with their engines.

This study investigated the compatibility of gelled fuel with present day large transport airplane fuel systems. Gels made with FAA 1069-1 gelling agent were investigated. Both bench-type laboratory testing and large-scale testing were conducted.

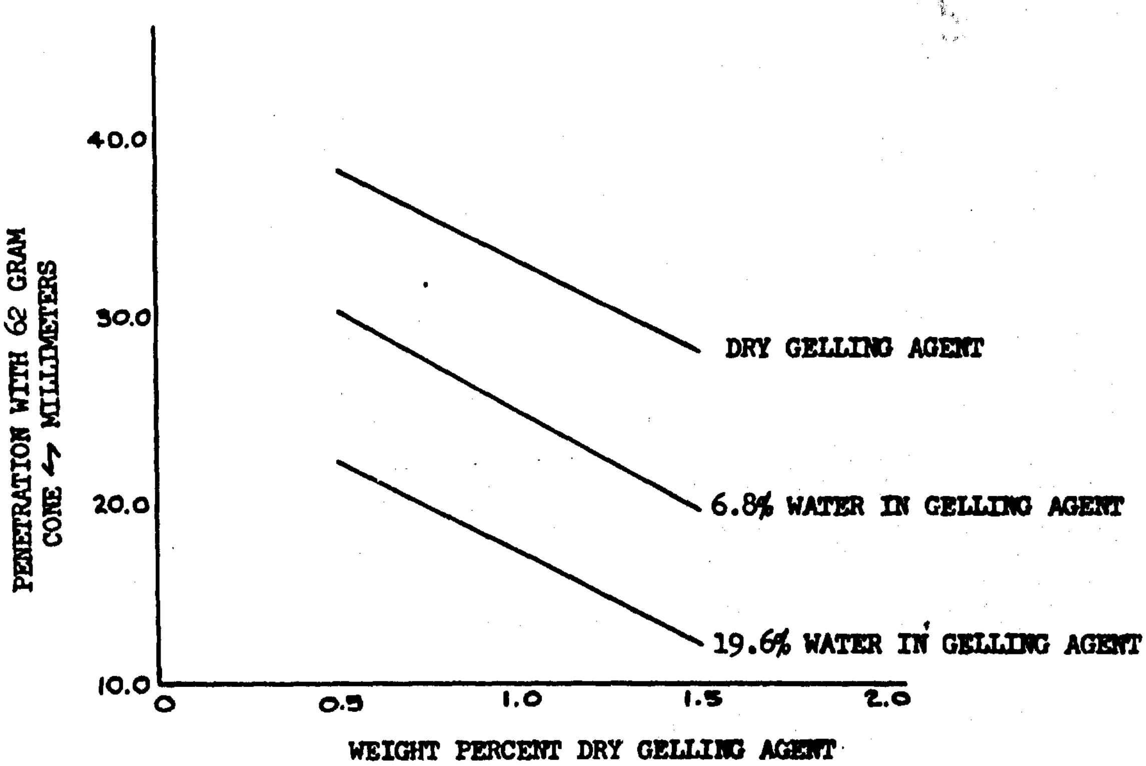
Laboratory Bench Tests

Since stiffness is a key factor in flowability, it was used to characterize each gel and was measured by the penetration of an inverted cone into a gel's surface. Determinations were made of the effect upon the stiffness and consistency of the gelled fuel of the following parameters:

- o Percent Gelling Agent
- o Amount of Total Water
- o Gelled Fuel Temperature
- o Mixing Temperature

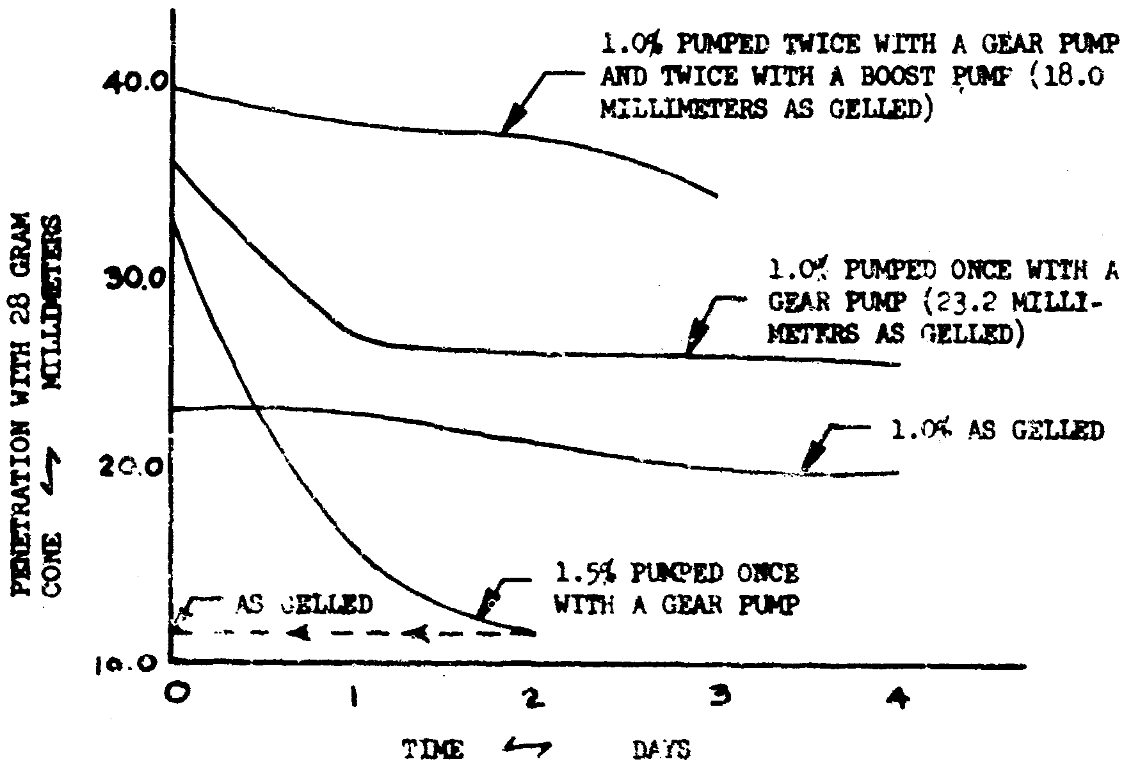
- o Cooling Rate During Gellation.
- o Pumping With A Vane Pump, A Gear Pump And A Centrifugal Pump.
- o Storage Time Before And After Pumping.

Small batches of gelled fuel were made using kerosene and varying amounts of FAA 1069-1 gelling agent. The kerosene was heated to 130°F to dissolve the gelling agent and the liquid mixture was allowed to cool to produce gellation. The stiffness of the gelled fuel was determined by the penetration of an inverted cone and the ASTM D-217 penetrometer. Th standard cone and two other lighter weight cones were used. Initial testing showed the stiffness of the gel to be affected by the water content of the final gel as shown below.



Pumping the gelled fuels tends to break their structure, releasing small amounts of liquid fuel and d:cr... ..ng their stiffness. Centrifugal, gear and vane pumps were used. The centrifugal pump caused the greatest decrease and the vane pump the least decrease in stiffness. The centrifugal pump has difficulty in maintaining suction.

The effect of time upon gel stiffness is shown below.



Gels which had been extensively pumped and severely broken would stiffen with time. This time period may be of the order of two or more days, but as seen in the flowability tests, only fo... hours were required for an otherwise flowable gel to stiffen enough so as ... ... flowable.

Samples of both pumped and unpumped gels were subjected to a temperature spectrum of -45°F to 110 115°F. The stiffness of these gels increase with a decrease in temperature.

A 1.0% gel was tested for corrosion characteristics with aluminum, cadmium-plated steel, magnesium, and steel. The metal surface of the cadmium plated steel was darkened but no pitting occurred and this was the only metal of the four to be significantly affected.

When tested for micro organism growth support the gelled fuels behaved similarly to Jet A kerosene.

Large Scale Tests

These tests were conducted to determine the effects of airplane environment on the gelled fuel and on the gelled fuel's performance in the airplane. A simulated section of 727 integral wing tank was used as a test bed.

Present fuel system design requires the fuel to flow by gravity to the fuel tank boost pump. Gels with different levels of stiffness were tested to relate gel stiffness to flowability. A 707 boost pump with a vapor eliminator was mounted on the tank for pumping out the fuel.

Liquid kerosene was used to provide a baseline. About two gallons of unavailable fuel remained in the tank. In these tests the gels are labeled as being "as gelled", "pumped once", 'pumped twice", etc. Pumped 0.7% gels would flow to the pump but about 12-14 gallons of gel were unavailable. When a 1.5% pumped gel, having a penetration of 33.0 millimeters with 28 gram cone, was pumped out 50% of 60 gallons

of gel was unavailable. Neither a 0.5% "as gelled" gel, nor a 1.5% pumped-once gel which had lain for four hours after being pumped into the wing tank would flow to the pump. The former registered a penetration of 23.0 millimeters and the latter 25.0 millimeters with the 28 gram cone.

The results of this testing are tabulated below.

% Gel	Times Pumped	Flow Rate, G.P.M.	Unavailable Fuel Left in the Tank, Gallons	Differential in Height Across Baffle, Inches: Prior to Pumping	Differential in Height Across Baffle, Inches: During Pumping	Consistency: Penetration With 28 Gram Cone, Millimeters	Consistency: Viscosity at 77°F., Centipoise
0.0		44.0	2	0.0	0.875		2
0.0		32.2	3	0.0	1.0		2
0.0		31.2	3	0.0	1.125		2
0.5	0		>95%	0.0		23.0	
0.5*	0		>95%	0.0		23.0	
0.7	1	30.4	17.5	1.5	3.0	38.0	
0.7	1	29.6	14.2	1.5	3.0	36.5	
0.7	3	14.8	12.3	0.25	1.5		112
0.7	3	14.9	12.0	0.25	1.0		60
1.5	1	14.4	28	1.5	4.0-6.0	33.0	
1.5	1		>95%			25.0	

* The angles of inclination in all cases were between two and four degrees fore and aft angle and three and six degrees lateral angle except for this case in which the angles were eight degrees and ten degrees.

For the vibration testing the simulated tank was mounted on the end of a 230-inch moment arm and subjected to a vibration spectrum consisting of a three-cycle per second frequency and a 0.0 to 5.4-inch double amplitude.

The consistency of the pumped gel is not affected by the low frequency vibration unless the double amplitude exceeds three inches. At this level it is weakened by the agitation induced by the vibration.

The unpumped gel was deformed by the inboard and outboard sloshing motion of the gel. This sloshing action induced bleeding of liquid fuel from the gel at the bottom of the tank.

A vertical cylindrical tank filled with about 100 gallons of gelled fuel was used for the pumpdown testing. The 707 boost pump with a vapor eliminator and using a snorkel type inlet was successful in pumping a pumped gel out of the pumpdown chamber at sea level pressure. However, at a simulated altitude of 42,000 feet (2.4 psia) the pump was able to pump only 35 of the 100 gallons out at approximately seven gallons per minute before the flow virtually stopped. This left about 65 gallons of gel having a head of 2.5 feet over the pump inlet in the tank. When the simulated altitude was reduced to 18,000 feet (7.33 psia) the remaining 65 gallons of gel was pumped out at a flow rate of about sixteen gallons per minute.

Conclusions

The penetration number of a gel is a function of both the percent gelling agent used and the water content. Thus strict moisture control would be required to manufacture gels with consistent penetration values. Pumping a gel reduces its penetration number markedly and variously. A pumped gel recovers stiffness with time.

From the results of the flowability testing in the wing tank section, a penetration level of 33.0 millimeters with the 28 gram cone is considered to be the upper limit of stiffness which will allow flow to the boost pump at sea level pressure.

A pumped gel with a penetration level of 33.2 millimeters with the 28 gram cone could not be pumped out of a tank at the low suction heads existing at an altitude of 42,000 feet (2.4 psia) when snorkel pump inlets are used.

Low frequency vibration of a period and amplitude experienced by a wing tank during gust loads will cause liquid fuel to be formed from either pumped or unpumped gels.

The low temperature fuel tank environment which is a characteristic of subsonic flight would aggravate any problem induced by the gel's stiffness.

This gel cannot be classed as a possible candidate for use in conventional transport airplanes because of its unpredictable stiffness.

III. INTRODUCTION

A fatal airplane crash is sometimes accompanied by a large post crash fire, caused by fuel being spewed out of ruptured fuel lines and/or fuel tank structure. This results in an aerosol mist of air and fuel and a pool of fuel near the airplane. The aerosol mist is subsequently ignited by hot engine parts, hot exhaust, a friction spark or other ignition source which might be present. The burning mist ignites the fuel spilled on the ground. Sometimes, the fire claims lives of those surviving the impact. In order to save those lives, stiffened fuels have been proposed to reduce both the aerosol mist and the fuel spill following a crash. The two types of stiffened fuel under consideration are emulsified fuel and gelled fuel.

The concept of using these fuels in airplanes has emerged gradually. Initially, the Army was investigating the feasibility of instantaneously gelling the fuel in the tanks just prior to an impending crash. After this concept was abandoned, the idea of transporting the fuel in the gelled state and then reconstituting it to liquid form prior to its use was investigated. This gave way to the concept of using the gelled fuel in the airplane in the "as gelled" state. The Federal Aviation Agency is interested in this aspect of thickened fuels and is considering the possibility of their use in commercial transport airplanes.

Both the Army and the FAA have funded research programs on the investigation of gelled and emulsified fuels. At this time the Army is concentrating their efforts in the emulsified fuel area, while the FAA leans toward gelled fuels. The FAA contracted The Western Company to develop and test fuels gels for their feasibility in reducing crash fire hazards. This work resulted in the formulation of a gelling agent designated FAA 1069-1 and is reported in Reference 1.

The FAA has also let two contracts for further development and testing of gelled fuels as well as emulsified fuels.

Most of the work previously accomplished on gelled fuel has been the determination of its crash safety aspects and its compatibility with aircraft engines. At the time this work was undertaken, hardly any investigation of the compatibility of the airframe with gelled fuel had been accomplished, and that was the object of this investigation. Gelled fuel made with FAA 1069-1 gelling agent was examined to determine how much stiffness the present airplane fuel system can accept without reducing flight safety. The study involved the determination of the factors affecting this stiffness so that its constancy and homogeneity could be assured. The gel was also investigated for side effects which could reduce flight safety.

The laboratory setup and test equipment and apparatus are shown and described. The methods of determining stiffness and the parameters affecting stiffness are discussed. The test data concerning these parameters are presented in Reference 2. A description of the tank mockup is given, and an analysis of the testing done in the tank mockup is made. Motion pictures taken of most of the testing in the tank mockup are available.

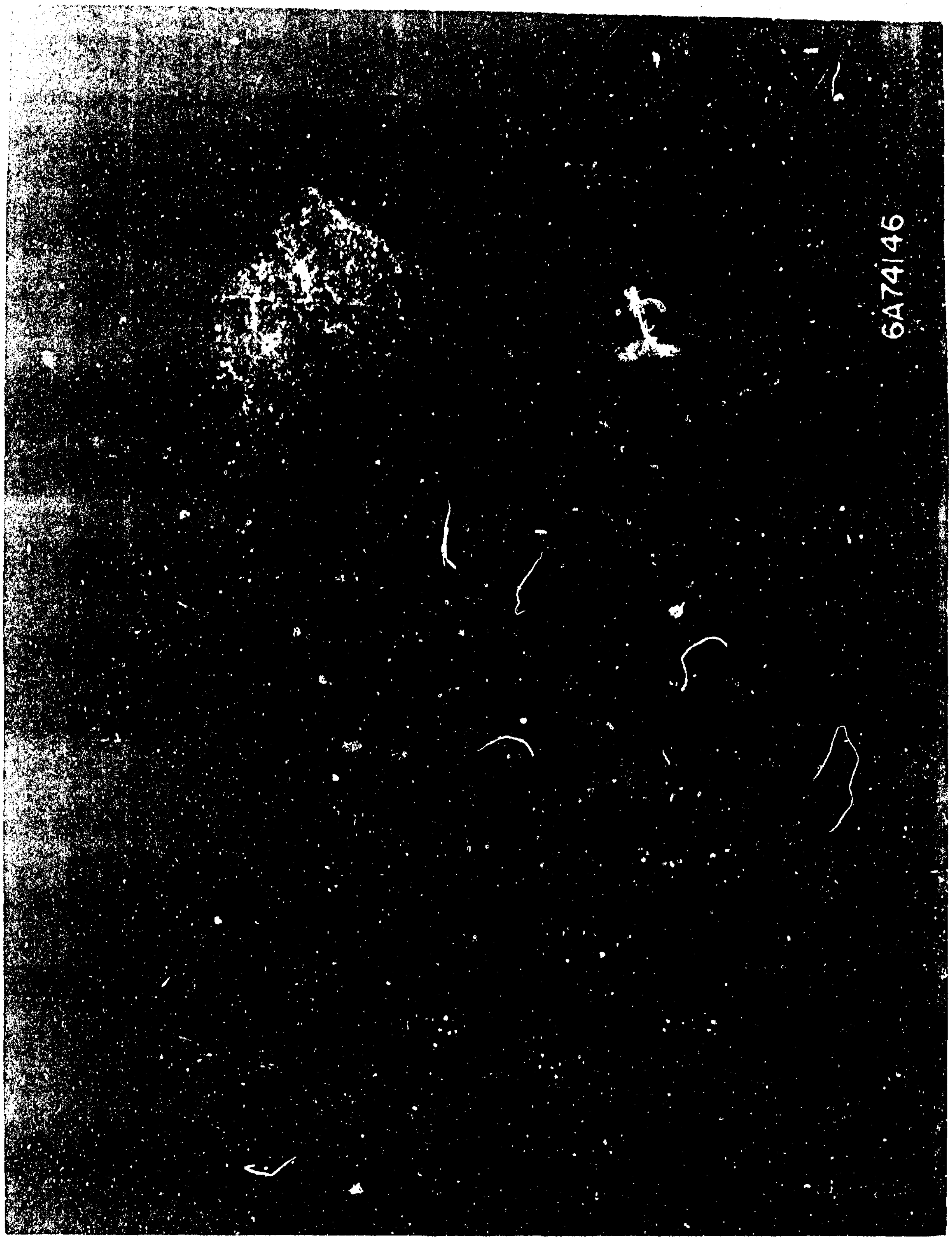
IV. TEST PROGRAM

A. MODEL AND TEST APPARATUS

The gelling agent used was FAA 1069-1, which is a hydrocarbon, N-coco-γ-hydroxy-butryamide (CHBA), developed by the Research Division of The Western Company (Dallas, Texas). Normal water content of the agent is 6% and adjusted pH is 9.0. The fuel is heated to 130°F, the agent is dissolved into it and the mixture is allowed to cool. Gellation sets in at about 125°F. As shown in Figure 1, the gelling agent is a waxy soap-like substance which will readily dissolve in the warm liquid fuel. The gelled fuel made with this gelling agent is a firm opaque substance with a slightly moist surface. In the "as gelled" state it resembles jello while the pumped gel is similar to "applesauce". Jet A kerosene was used in these tests.

The ASTM D-217 penetrometer shown in Figure 2 was used to determine the consistency of the gelled fuels. The standard penetrometer cone has a total weight of 150 grams but since this was too heavy for some of the softer gels, two light-weight cones were made. One was an aluminum cone with a total weight of 62 grams and the other was a plastic cone with a total weight of 28 grams. These are 90° cones with a 30° needle point. The penetration of these cones into the gel in a five second interval is measured. The penetration is inversely proportional to gel strength. The viscosity of the pumped gels, which were too fluid to be measured with the penetrometer, was determined by use of the Saybolt viscometer which is shown in Figure 3. The time required for the efflux of a 60 milliliter sample of gel was obtained and the viscosity was determined from this by use of ASTM procedures D2161-63T and D1745-63.

Two of the three small pumps used to work the gels in the laboratory are shown in Figure 4. The fuel was gelled in the hopper or put into the hopper after gellation and then pumped out, using a follower plate where needed.



CALC	BURK	6/1/67	REVISED	DATE	FAA 1069-1 GELLING AGENT	FIGURE 1
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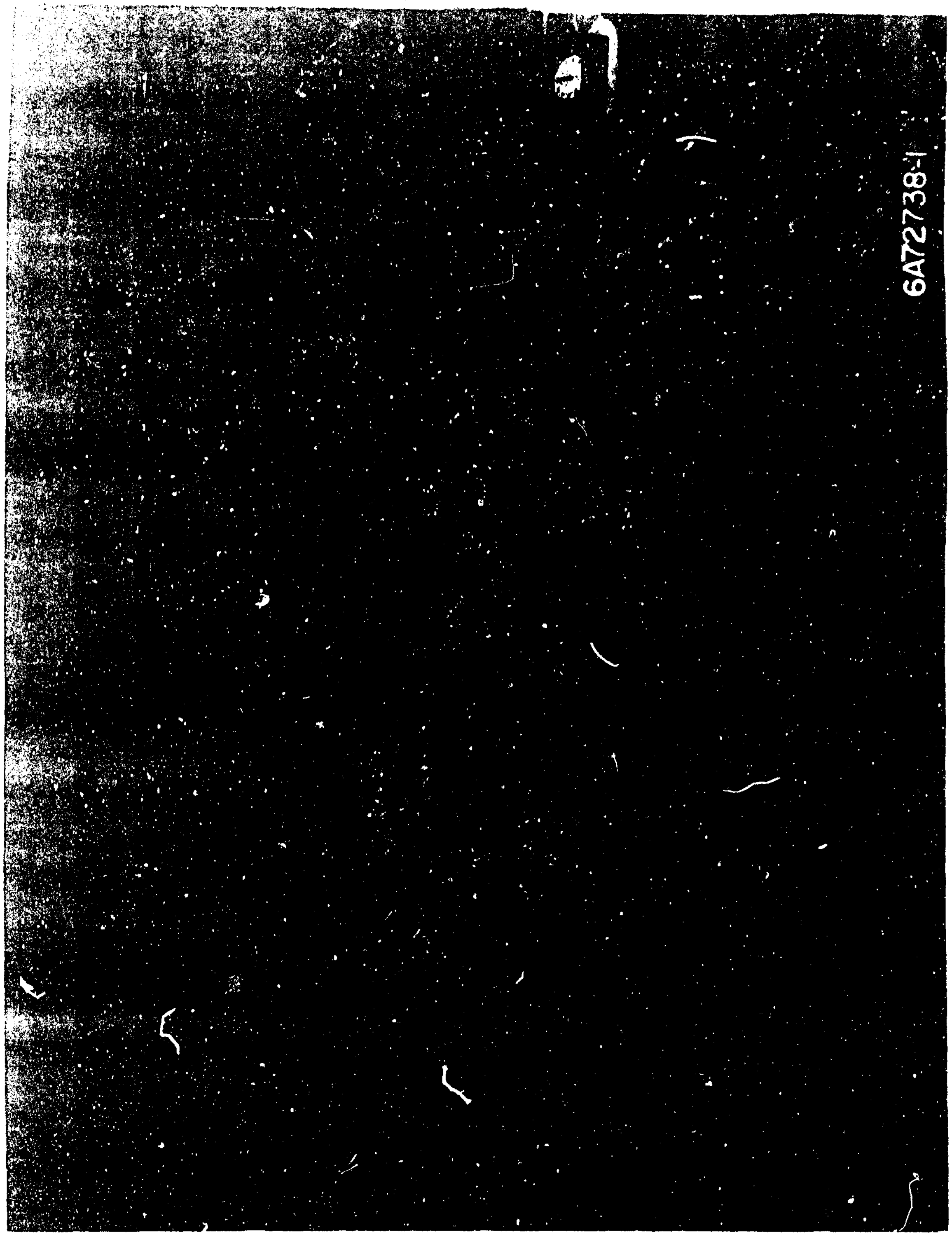

CALC	BURK	8/1/67	REVISED	DATE	A.S.T.M. PENETROMETER USED IN CONSISTENCY TESTS WITH SAMPLE CUPS CONFORMING TO A.S.T.M. SPECIFICATIONS	FIGURE 2
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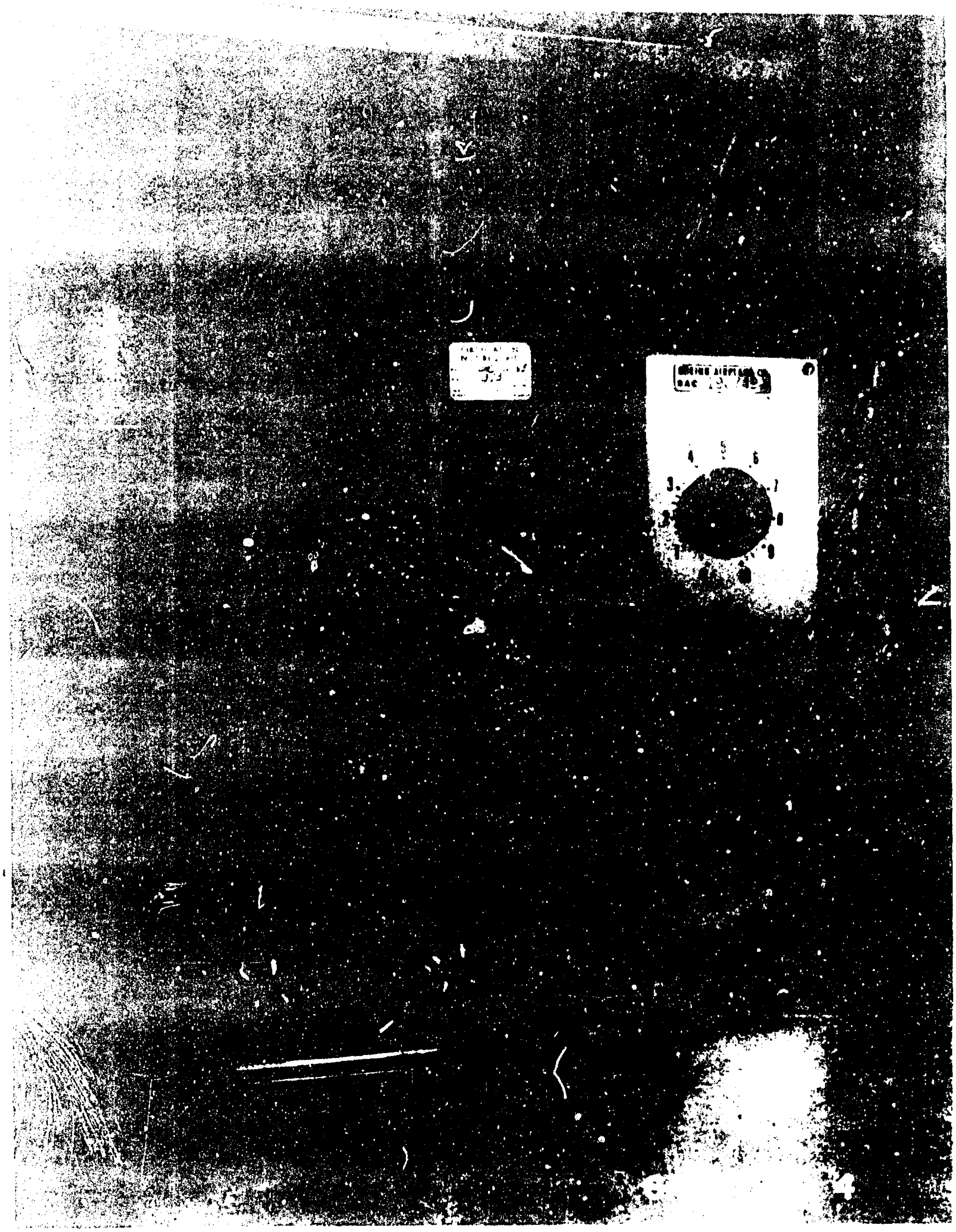

CALC	BURK	9/1/67	REVISED	DATE	SAYBOLT VISCOMETER USED IN CONSISTENCY TESTS OF PUMPED KEROSENE GELS	FIGURE 3
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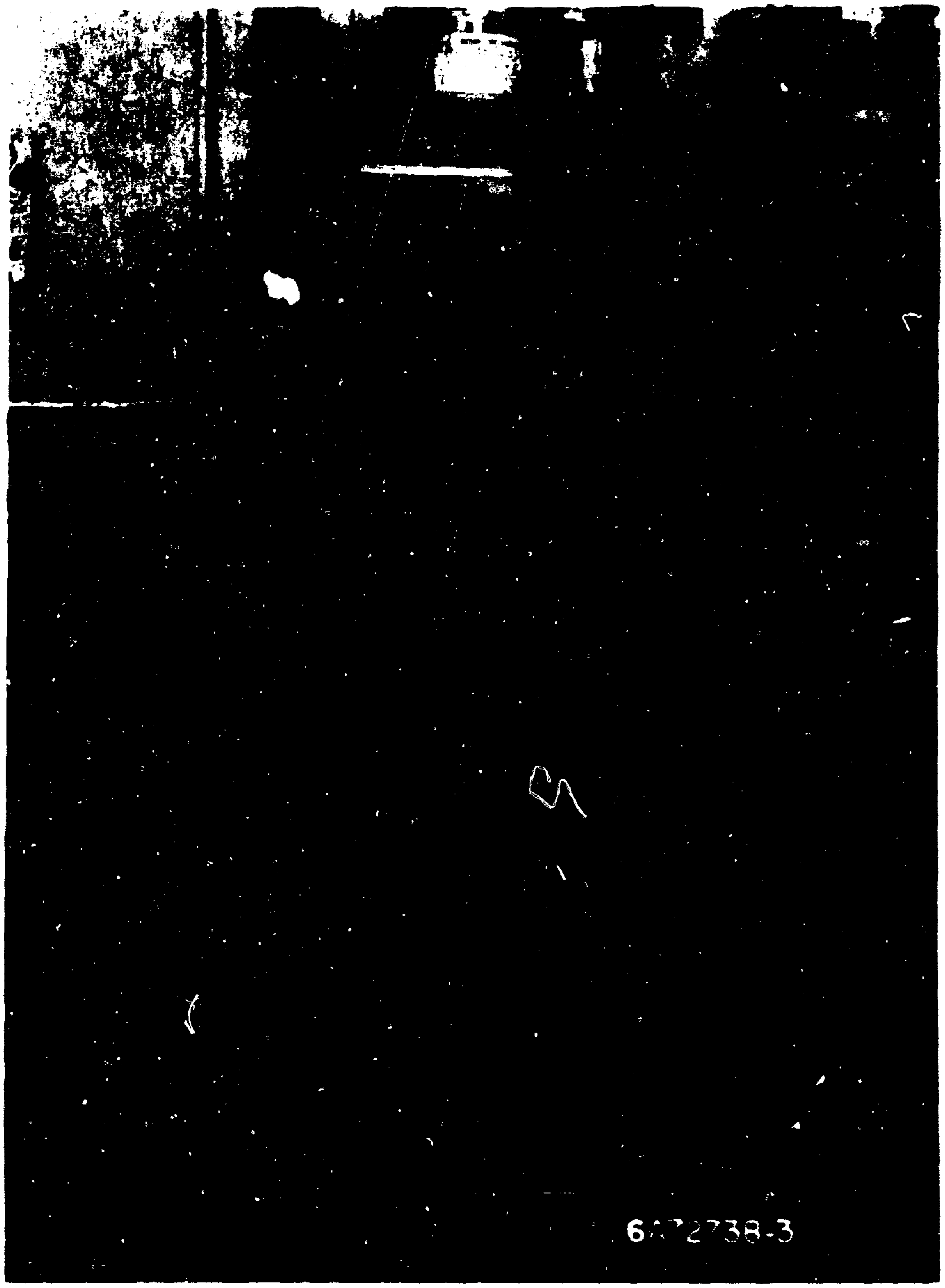

CALC	BURK	6/1/67	REVISED	DATE	SMALL CENTRIFUGAL PUMP AND GEAR PUMP USED IN GEL PUMPING TESTS	FIGURE 4
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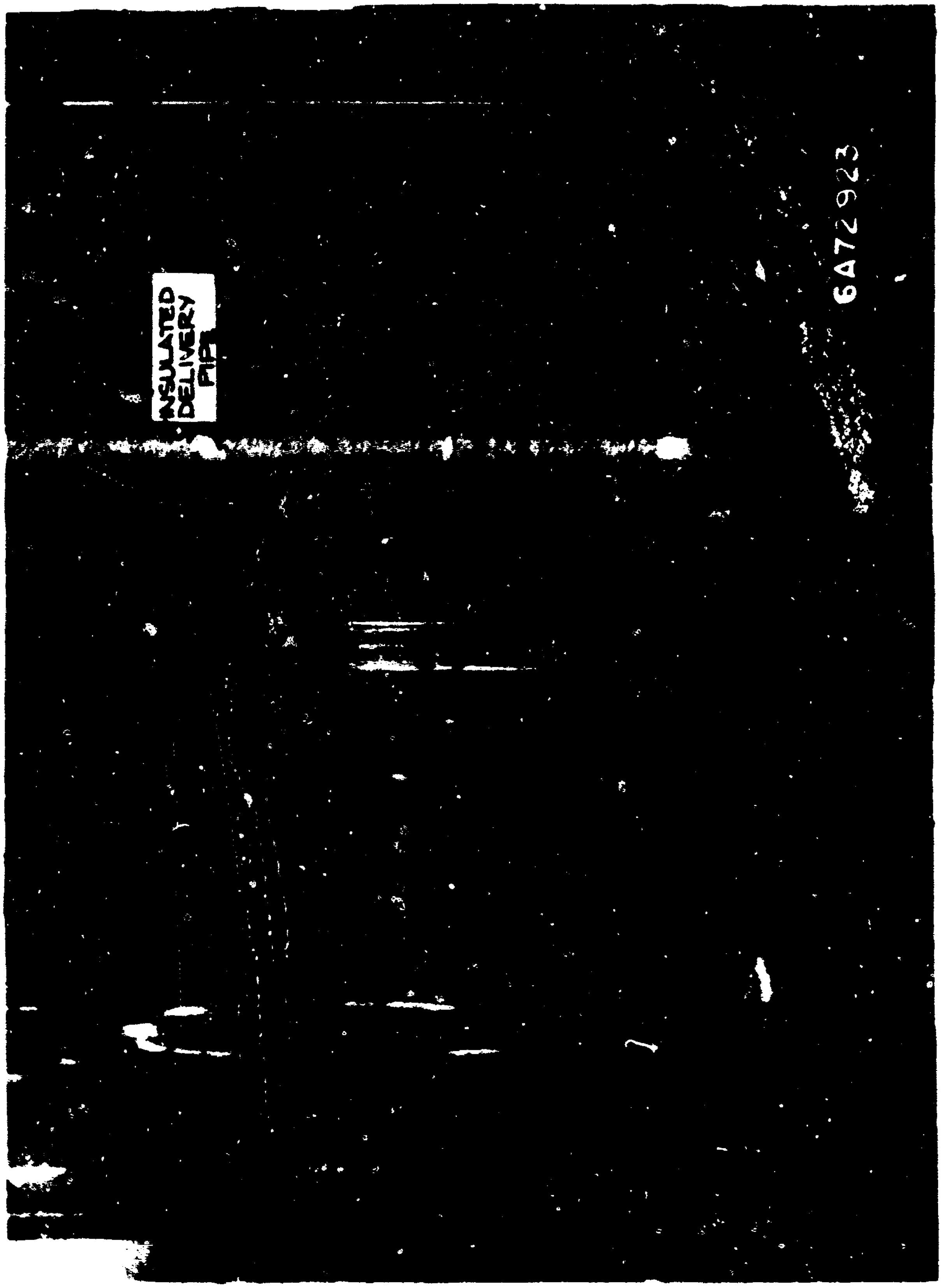
Two 13 inch by 9 inch by 2 inch cake pans, one aluminum and one Teflon coated, were used to determine the effect of a non-wettable surface on the gel's flowability characteristics. Baffles divided each pan into two unequal sections, and holes in these baffles simulated holes in ribs or stiffeners.

The large scale mixing equipment and the pumpdown tank are shown in Figure 5. The mixing tank has a capacity of more than 100 gallons. It has a removable unit consisting of a coil of copper tubing for heating and cooling the fuel and a paddle wheel for keeping the fuel well mixed. Thermocouples were located on both sides of the mixing tank at various depths. An air-driven gear pump is used to pump the gel out of the mixing tank.

The pumpdown tank has a capacity of about 100 gallons and provides a four-foot head of fuel at the pump inlet. Plexiglass windows are located on the top and the side of the tank. This tank is capable of withstanding a vacuum of 30 inches of mercury and the piping and valving allows a vacuum to be maintained constant while gel is being pumped out with the 707 auxiliary boost pump. The pump has a vapor eliminator and a snorkel-type inlet similar to those used for the 727 airplane. Small sections of plastic tubing allow visual observations of the gel upstream and downstream of the boost pump.

The gelled fuel was tested for its ability to flow in the test section shown in Figure 6. This simulated wing tank was designed to represent a section of the Boeing 727 integral wing tank as shown in Figure 7. The test tank represents 4.5% of the 205 square foot area of the number one wing tank being simulated. The total capacity of the wing tank is 1797.5 gallons, of which only 4.5 gallons are trapped or unusable in flight. This results in a usable capacity of 1793 gallons, or 99.7 percent of the total. The test section can



CALC	BURK	8/1/67	REVISED	DATE	GENERAL VIEW OF MIXING AND PUMP-DOWN TANKS WITH GEAR TYPE TRANSFER PUMP AND CENTRIFUGAL BOOST PUMP	FIGURE 5
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CALC	BURK	8/1/67	REVISED	DATE	POSITION ADOPTED BY 1% KEROSENE GEL IN CENTER SECTION OF TANK WHEN PLACED AT 30° ON END	FIGURE 6
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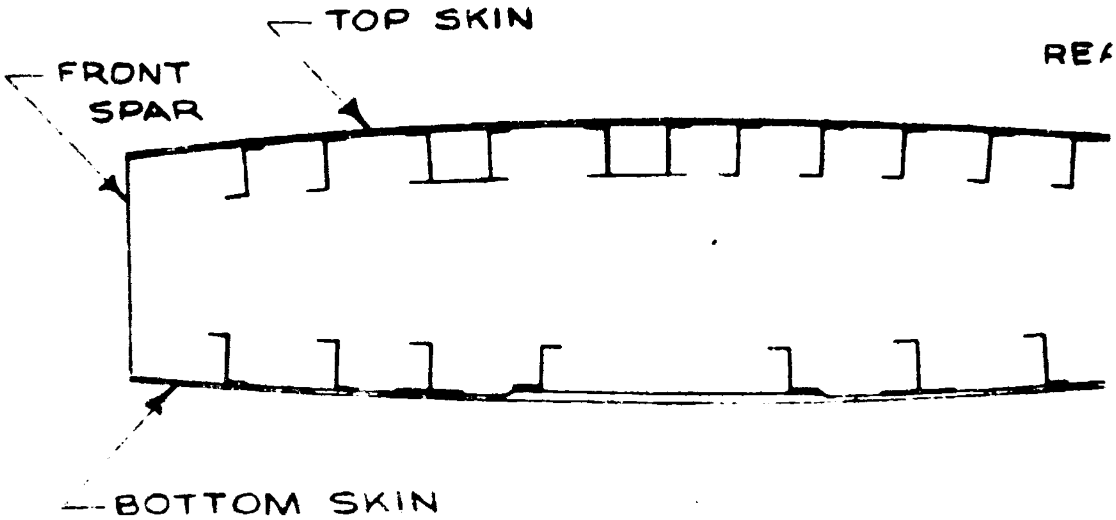
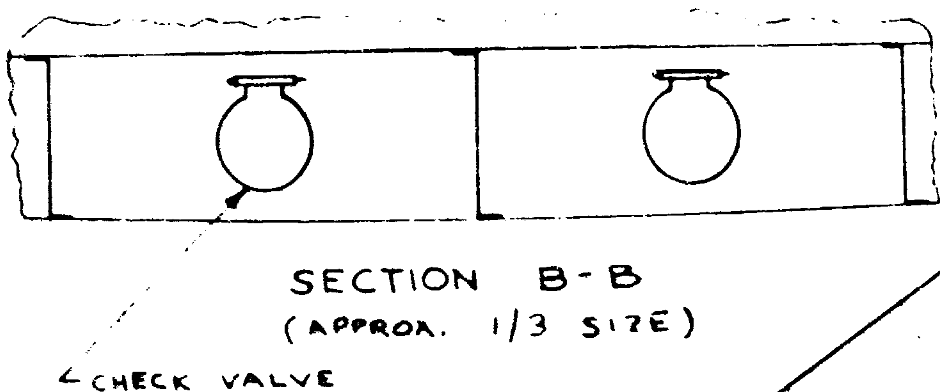


SECTION A-A
(1/10 SIZE)



SECTION B-B
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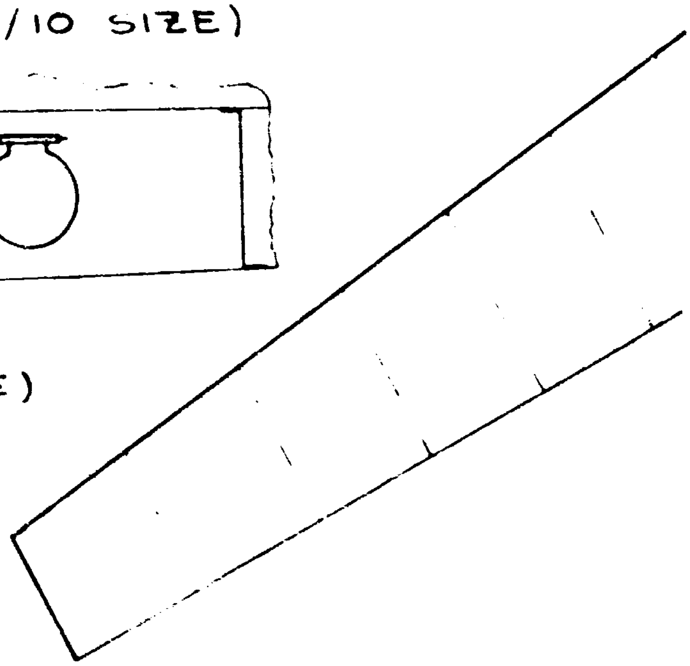

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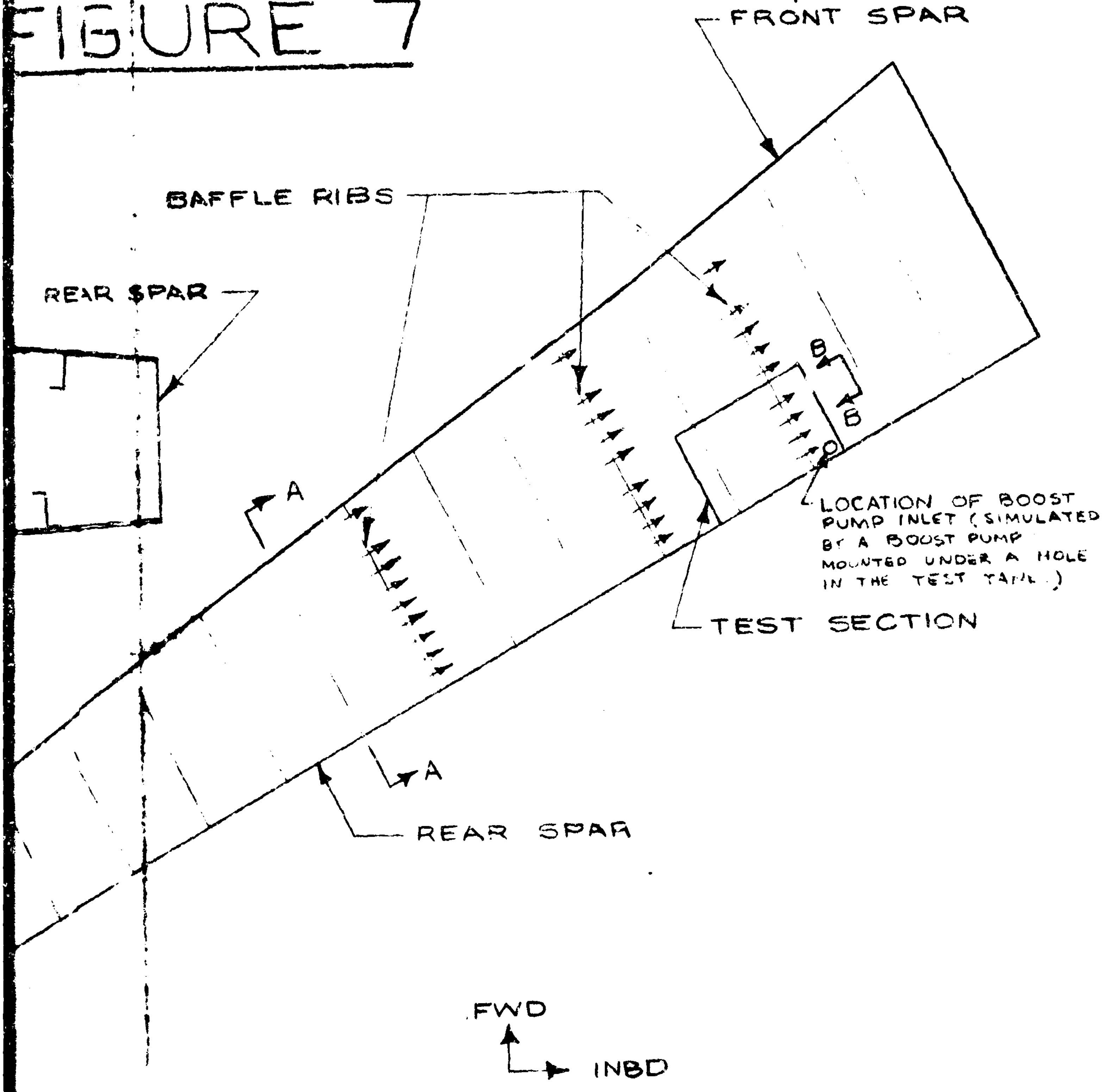
FIGURE 7



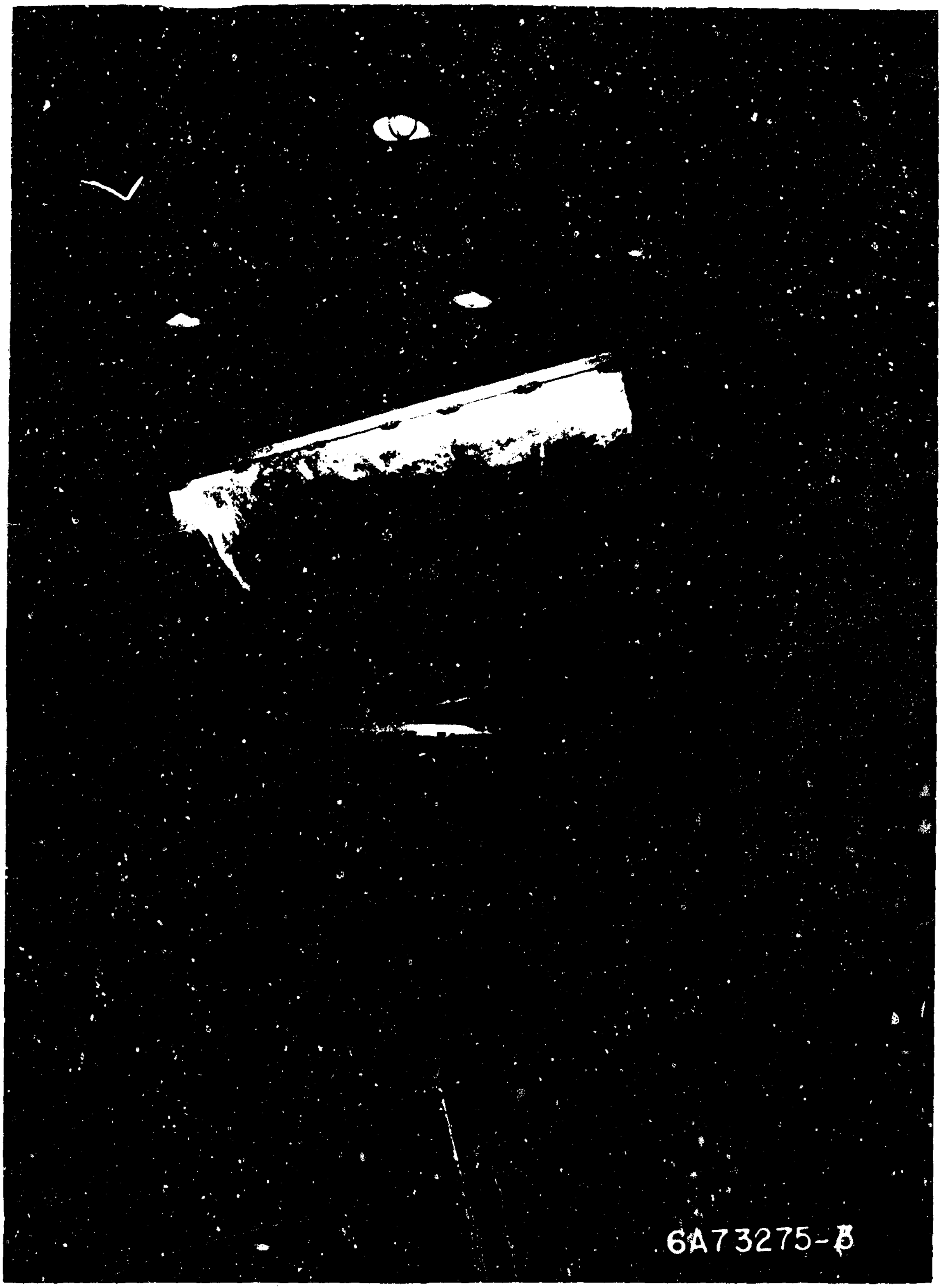
727 WING TANK
(1/40 SIZE)

hold about 100 gallons, but usually less than 70 gallons was used for testing.

The construction of the integral wing tank includes ribs about every 27 inches. Three of these ribs are baffled and have flapper type check valves in the baffle to prevent fuel from flowing outboard and away from the pump inlet. Spanwise Z-type stiffeners are spaced about 7 inches apart on the top and bottom skins. The stiffeners have small limber holes in certain places to allow fuel which would otherwise be trapped between stiffeners to flow to the pump inlet. The test section was designed to include one of the three baffle ribs and a pump inlet. This simulated tank thus includes one of the areas of the integral wing tank with all types of flow restrictions. The fuel has to flow through the cutouts in the rib for the stiffeners, and then through the baffle check valves to get to the pump inlet. After some initial testing had been accomplished, a section of stiffener adjacent to the pump inlet was removed to provide multiple flow paths, more closely resembling airplane conditions.

The tank was mounted on a gimballed table as shown in Figure 8, so it could be set at various angles in both a forward and a spanwise direction in order to approximate different flight attitudes. The 707 auxiliary boost pump with vapor eliminator was mounted on the tank and used to pump the fuel out of the tank. A gage was mounted on the baffled rib to allow a visual measurement of the differential in fuel height across the baffle both prior to and during pumping.

The simulated wing tank can be mounted on a low frequency, high amplitude vibration rig shown in Figure 9. This rig, built up from a "tinker toy" set of 8 and 12 inch I beams, allows vertical motion at the end of a 230 inch moment arm. A hydraulic actuator is used to produce a sinusoidal



CALC	BURK	6/1/67	REVISED	DATE	GIMBALLED TABLE, SIMULATED WING TANK AND CENTRIFUGAL BOOST PUMP	FIGURE 8
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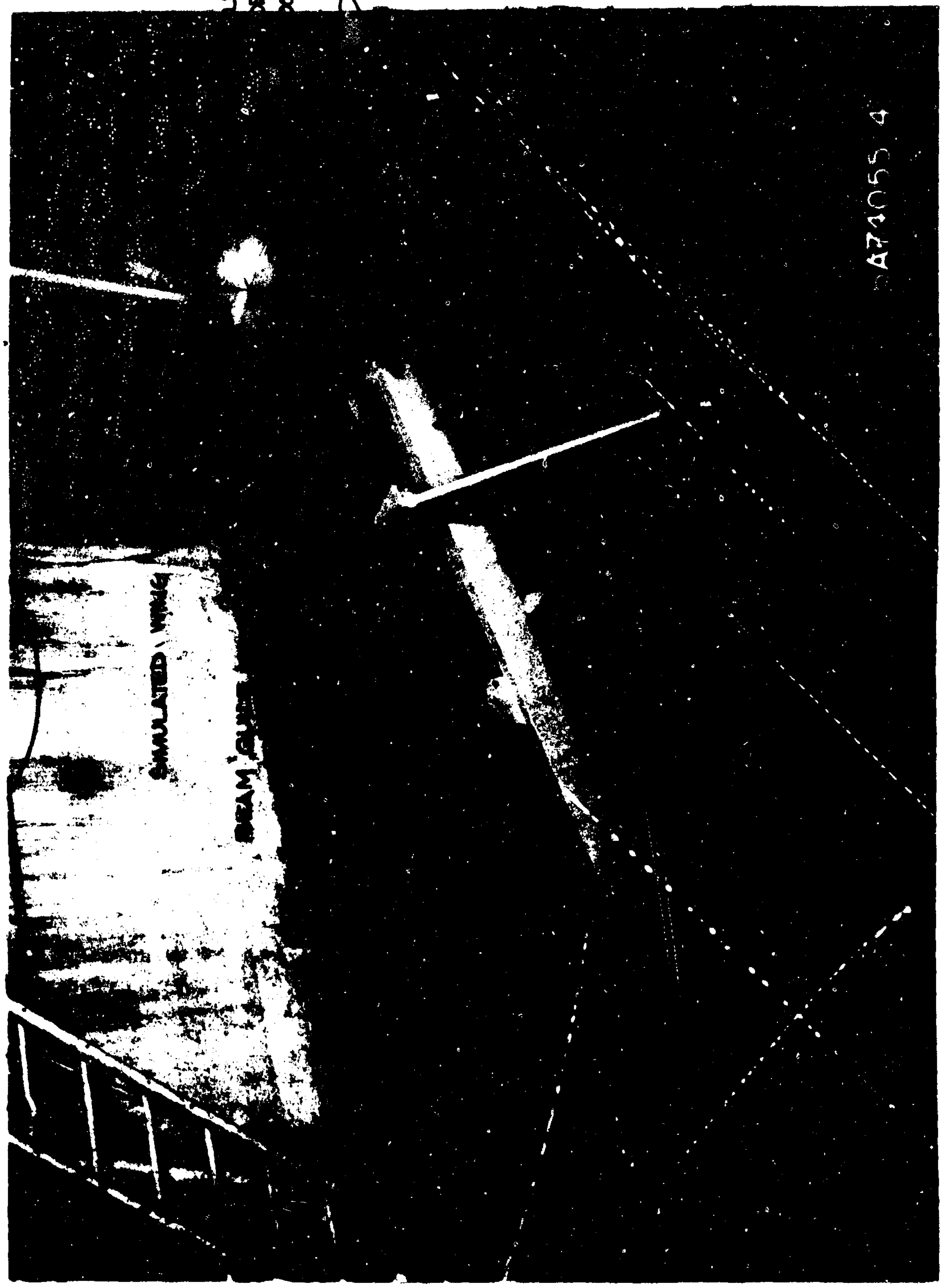

CALC	BURK	6/1/67	REVISED	DATE	SIMULATED WING TANK MOUNTED ON VIBRATION TEST RIG	FIGURE 9
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vibration. The outboard end of the moment arm where the tank mock up is mounted represents wing station 760 which is the outboard end of the surge tank. In order to obtain enough hydraulic fluid flow to obtain the maximum double amplitude of 5.4 inches and 3 cycles per second frequency, an accumulator was needed. Instrumentation included a linear transducer and an accelerometer.

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B. TEST PROCEDURE

The FAA 1069-1 gelling agent was obtained from The Western Company along with mixing instructions. Some of the variables affecting the strength of the gelled fuel were associated with the mixing procedure. These included the amount of total water in the gelled fuel, the amount of gelling agent, the temperature of the liquid fuel and the length of time at that temperature, the amount of particulate matter in the fuel, and the rate of cooling during gellation. This investigation also included the effect upon gel strength and consistency of the following:

- o Pumping the gel with different types of pumps
- o The number of times pumped
- o The length of time after pumping and before consistency testing
- o Filtering the pumped gel
- o Gel temperature
- o The amplitude, frequency and duration of vibration

The gelled fuel was tested for corrosion characteristics as well as microbiological growth support. The effect of altitude upon gel consistency and pumpability was also determined. The ability of different strength gels to feed a pump inlet in a typical integral wing tank was studied. The effect on the flow capabilities of gelled fuels of a non-wettable surface such as Teflon was also investigated.

Approximately one gallon batches of gelled fuel of various strengths were made for the small scale laboratory testing. These included gels made with 0.5, 1.0 and 1.5 per cent by weight gelling agent. The liquid kerosene was heated to the gellation temperature of 130°F by use of a water bath. The required amount of FAA 1069-1 gelling agent was finely divided and added to the

hot fuel which was kept at 130°F until the gelling agent dissolved. The liquid mixture was allowed to cool and gel in three or more penetration cups and special containers as needed for other tests. Using three or more samples, an average penetration was obtained.

Variations from this general small scale mixing procedure were made to check the effects of various parameters. In order to determine the effect of water content of the gelled fuel upon the gelled fuel strength, the gelling agent was dried and predetermined amounts of water were added. A fuel temperature other than 130°F was used in some cases and this resulted in a variation in gel strength. The gel strength is also affected if the liquid gelled fuel is held at the gellation temperature for a period exceeding that required for dissolving the gelling agent. The rate of cooling during gellation has an effect upon the gel strength and this was varied. Another test involved the addition of Arizona road dust to the heated liquid fuel prior to gellation.

When the liquid gelled fuel had gelled and reached room temperature, the penetration was determined for each of the samples with a suitable cone. For correlation purposes the penetration of various strength gels was measured with both the 150 and 62 gram cones or with the 62 and 26 gram cones.

For the pumping tests, the gelled fuel was put into the hopper either before or after gelling. Each pump was tested independently with a fresh batch of gel and the consistency of the pumped gel was determined with either the penetrometer and/or the Saybolt viscometer, depending on its consistency. Three different pumps were used and for two of the three pumps the samples were pumped repeatedly until further pumping had virtually no effect upon the viscosity of the gel. The consistencies of some pumped gels was measured with both the Saybolt viscometer and the 28 gram cone. One gel was pumped with the

gear pump through a 150 micron filter and compared with a sample of the same gel pumped with the gear pump without the filter.

Both pumped and unpumped gels were cooled to within 5° of the freezing point of the liquid fuel and the penetration level was checked at several points to determine the effect of temperature.

Some gels were divided into two parts prior to gellation. After gelling, one part was pumped more than once and nothing was done to the other part. Both parts were then liquified and regelled to see what effect this would have on regel strength and consistency. Some gels were tested for consistency as soon as they cooled to room temperature and then were periodically rechecked to determine the effect of time upon stiffness. This same procedure was used for other gels except that they were pumped one or more times after gelling.

The gel was tested for its corrosion characteristics upon cadmium plated steel, aluminum, steel and magnesium. The metals were selected and arranged per AMS 3150 C 4.14.3. One group of metals was immersed in 1% gel for 30 days and another group was half immersed in the gel with the other half of the metal coupon extending into the atmosphere above the gel. A comparison run was made using liquid kerosene. In both tests the metal coupons were weighed before and after testing with the gel and the corrosion products were removed with benzene and acetone washings.

The gel was also tested for its support of microbiological growths. Gel samples of 0.2, 0.5, 1.0 and 1.5% gelling agent were exposed to an inoculum containing eleven different fungi. Also inoculated were 1 and 3% agar-water mixtures, 0.2, 0.5, 1.0 and 1.5% agar--fuel preparations, 1 and 3% gel-water mixtures and 10 milliliter aliquots of kerosene and kerosene plus 0.5% water. The agar and gel plates were incubated at 85°F and 95% humidity for 28, 60 and 90 day periods.

The plates were microscopically observed at the end of these periods as well as after 3, 7, 14 and 21 days.

The effects of a Teflon covered surface upon the flow characteristics of the gel were investigated. The angle was determined at which the gel would flow through a limber hole in a simulated stringer in the aluminum and Teflon-lined cake pans. Also, a 5 cubic centimeter sample of 1.0% gel was placed in each of the pans. Then the angle at which the sample will move down the pan was determined as was the time required to move 12 inches down the pan.

The large scale testing involved the use of 50 gallons or more of gelled fuel. To make these large batches, the liquid kerosene was put into the mixing tank and heated to 130° F by use of the steam coil. The paddle wheel in the bottom of the tank kept the kerosene well-mixed and the uniformity of the temperature was determined by thermocouples at various depths and on opposite sides of the mixing tank. The required amount of gelling agent was added to the kerosene when the temperature reached 130°F and this temperature was maintained until the gelling agent had completely dissolved in the kerosene. The steam coil and paddle wheel were then removed and the liquid gelled fuel was allowed to cool and gel. After the gel cooled to room temperature, a penetration sample was removed and then the gel is transferred to the pumpdown chamber or the simulated wing tank with the air-driven gear pump. The consistency of this once pumped gel is determined. After the gel was pumped into the pumpdown chamber, it was pumped out with the 707 auxiliary boost pump at sea level pressure.

A once pumped gel was tested under a vacuum to determine the effects of altitude. The pumpdown chamber was taken to a simulated altitude of 42,000 feet (2.4 psia) in steps and the evolution of air was observed. An attempt was made to pump the

gel out of the pumpdown tank using the same 707 boost pump. The simulated altitude was reduced as necessary to obtain flow. The flow rate was determined by periodically measuring the volume of fuel discharged as a function of time.

Flowability tests in the simulated wing tank were accomplished by pumping about 50 gallons of gel from the mixing tank, through a rubber hose, into the outboard section of the test tank. Thus flow was always toward the inboard, or pump end of the tank. The differential of fuel surface level on either side of the baffle rib was measured during fill, at rest, and during pump-out. This was one index of flowability. The gel was pumped into the test tank; (1) while still hot and allowed to gel; (2) after gellation to test the pumped condition; or (3) reused after a previous test to simulate a twice pumped gel.

Just prior to the flowability test the tank was set to the desired "roll" and "pitch" angles. The boost pump mounted in the test tank removed fuel at a predetermined rate during the flowability test, which terminated when the pump lost suction. Unavailable fuel was then measured, and constituted a second flowability index. Untreated Jet A kerosene was used to provide a baseline.

To determine the effect of vibration, the filled simulated tank was subjected to a low frequency, high amplitude vibration spectrum. A 1.0 percent "as gelled" gel was vibrated at a frequency of three cycles per second and a double amplitude range from 1.[illegible] to [illegible] inches for a total time of about 15 minutes. Then a pumped 1.0 percent gel was vibrated for about 6.5 minutes at a frequency of 3 cps and a double amplitude of from [illegible] to [illegible].6 inches. Full motion picture coverage of this testing was also obtained. The Photo Instrumentation Group has the motion pictures under file number [illegible] 728.

C. DISCUSSION AND RESULTS

1. Bench Tests

a. Consistency and Stiffness

The data shown in Fig. 10 were taken initially in an attempt to obtain a range of values for the consistencies of gels made with differing amounts of gelling agent. Each of the data points represents the average penetration of samples of "as gelled" gel made in the same container and poured into three gellation cups. The actual values vary from these averages by from ± .291% to + 3.36% and -3.48%. A greater penetration is indicative of a weaker gel. Because of the wide range of values from each of the different percentage gels and the overlapping of the ranges, an investigation of the effect of total water was begun.

It was determined that the gelling agent will equilibrate with the water content of the atmosphere surrounding it and since the strength of the gel is dependent upon the water content of the gelling agent this had to be taken into account. Tests were run with gelling agent containing from zero to 19.6% by weight of water. Figure 11 shows the results. Fuel used for these tests was predried.

The photograph in Fig. 12 shows a slump test of two samples of 1.0% gel, one made with 3.7 and the other with 1[illegible].0 percent by weight of water in the gelling agent; and one of the gellation cups from which they were removed. The greater slump was obtained with the 3.7% H_2O gel.

From these findings we conclude that the gel can be characterized by penetration alone, and that the penetration of a particular sample of gel is a function of both the percent gelling agent and the amount of total water in the gel.

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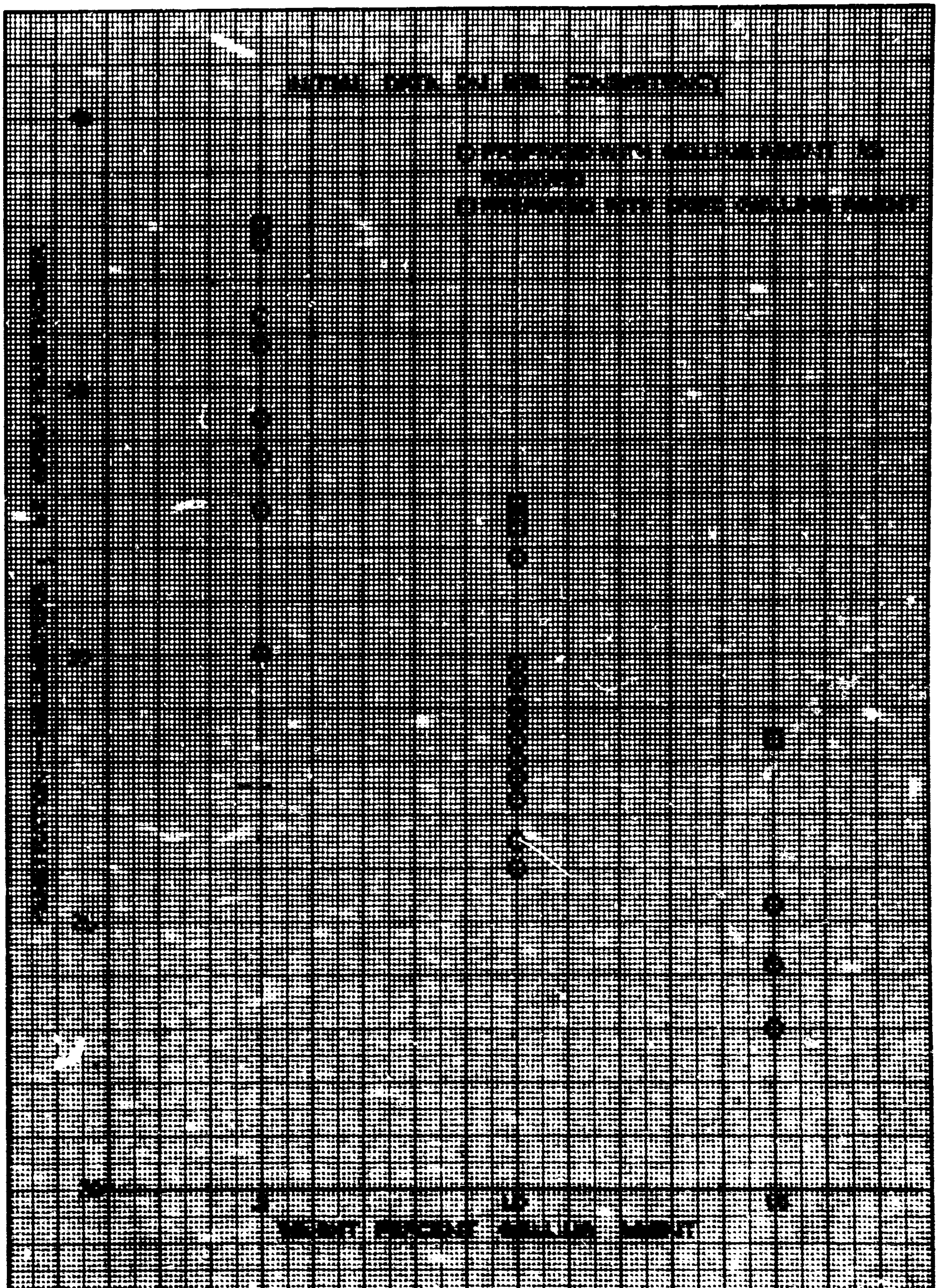
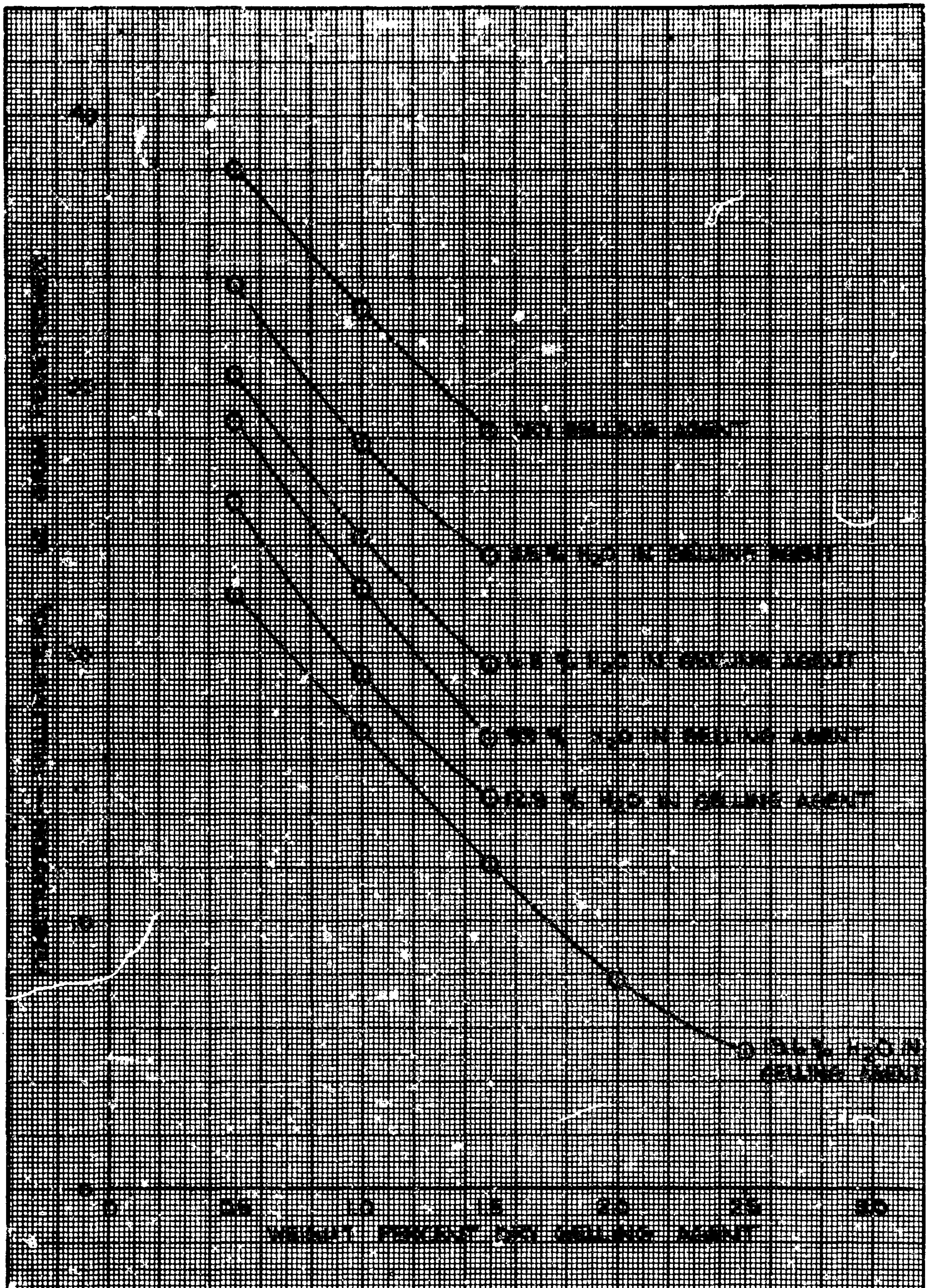


CALC	BURK	6/1/67	REVISED	DATE	STIFFNESS OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT AS INDICATED BY PENETROMETER - NO CONTROL ON WATER CONTENT OF GELLING AGENT	FIGURE 10
CHECK						
APR						
APR					THE BOEING COMPANY	



CALC	BURK	6/1/67	REVISED	DATE	EFFECT OF GELLING AGENT WATER CONTENT ON STRENGTH OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 11
CHECK						D6-15230
APR					THE BOEING COMPANY	PAGE 33
APR						

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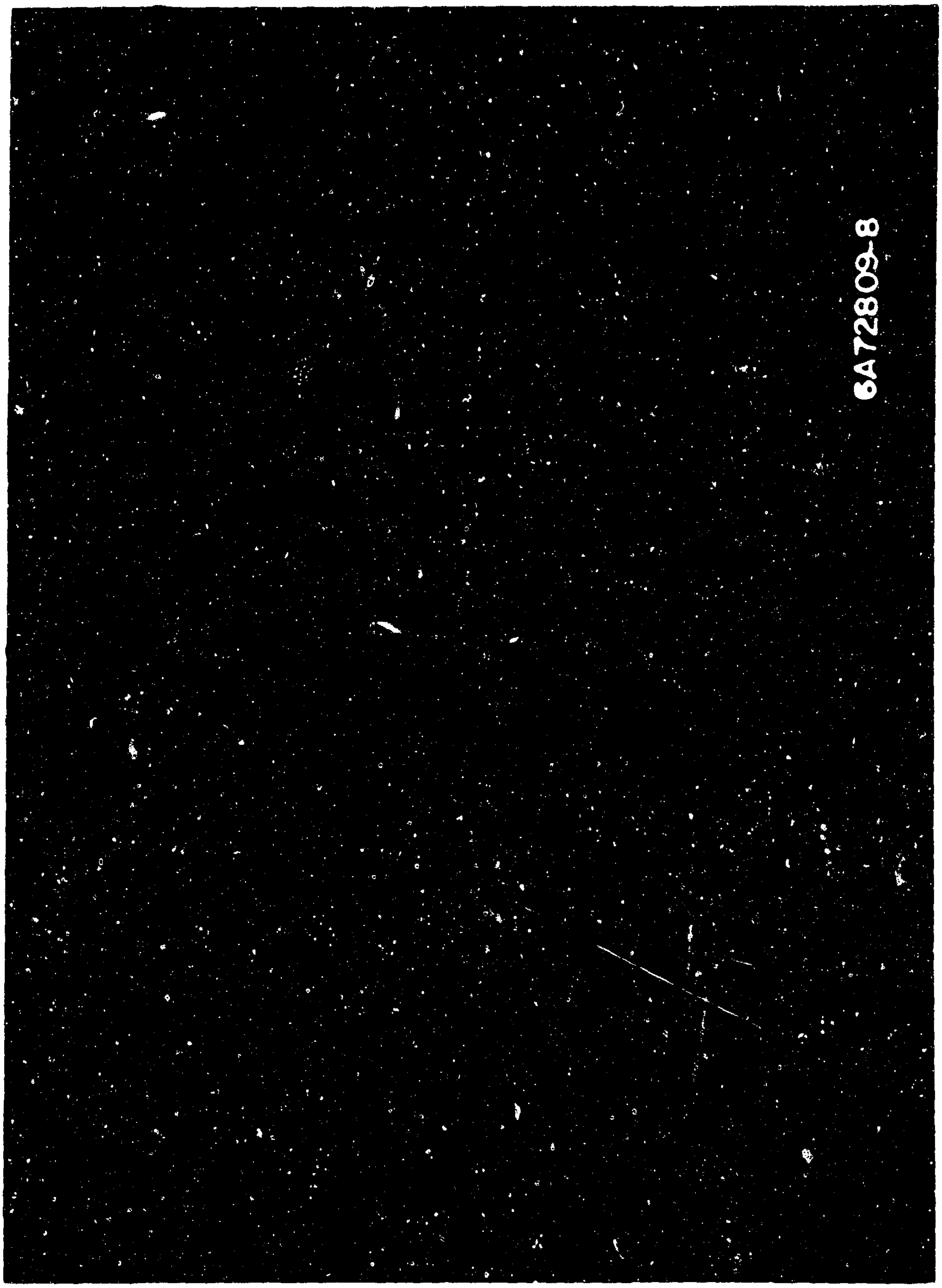

CALC	BURK	6/1/67	REVISED	DATE	SAMPLES OF 1% KEROSENE GEL PREPARED WITH 3.7% AND 14.9% BY WEIGHT OF WATER IN THE GELLING AGENT	FIGURE 12
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Some other parameters appearing to affect consistency were investigated and it is believed that these are in reality directly connected with the dependency of the gel consistency upon water content. During the testing program, some of the gels were liquified and regelled. The effects of this upon the consistency of pumped and unpumped 0.5 and 1.0 percent gels are shown in Table I. Upon regelling both the pumped and unpumped samples of the same initial gel have an identical penetration level but it is higher than the original gel if the regellation temperature is 130°F. However, if the regellation temperature was 120°F, then the regelled gels had approximately the same penetration level as the original gels. I think this could be due to the higher regellation temperature causing enough dehydration of the liquid gelled fuel to result in a weaker gel and a higher penetration level. In another test, part of a batch of gelled fuel was held at the gellation temperature of 130°F for about four hours after the gelling agent had dissolved. This sample of gel had a higher penetration level than the other sample which had been removed from the mixing vessel immediately after the gelling agent had dissolved. This would indicate a loss of water during the four hour hold at the gellation temperature. In most of the testing the hot liquid gelled fuel was allowed to cool by natural convection at laboratory room temperature. In order to determine the effect of the rate of cooling, two samples of the same gel batch were treated differently. A -60°F bath was used to cool one sample at a rate of 1.3°F/minute over the temperature range of 124°F - 85°F. The other sample was cooled at room temperature at a rate of about 0.7°F/minute over the same temperature range. Both samples were then allowed to attain room temperature and remain there for 24 hours. The gel which was rapidly cooled had a penetration of 31.8

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TABLE I

LIQUEFACTION AND REGELLATION DATA

Gel Characteristic	CONSISTENCY			
	Penetration of 62 Gram Cone, Millimeters	Saybolt Viscosity, Furol Seconds		
	As Gelled	Pumped with Gear Pumps	Pumped with Gear and Centrifugal Pumps	Pumped with Gear Pump and Twice with Centrifugal Pump
0.5% #1	30.0	---	---	---
0.5% #2	30.0	100	44	21
0.5% #1 Regel	35.0	51	18	15
0. #2 Regel	35.0	54	17	14
1% #1	25.0	---	---	---
1% #2	25.0	35.4 [1]	260	135
1% #1 Regel	31.0	135	70	42
1% #2 Regel	31.0	133	80	42

[1] Penetration in millimeters with 28 gram core.

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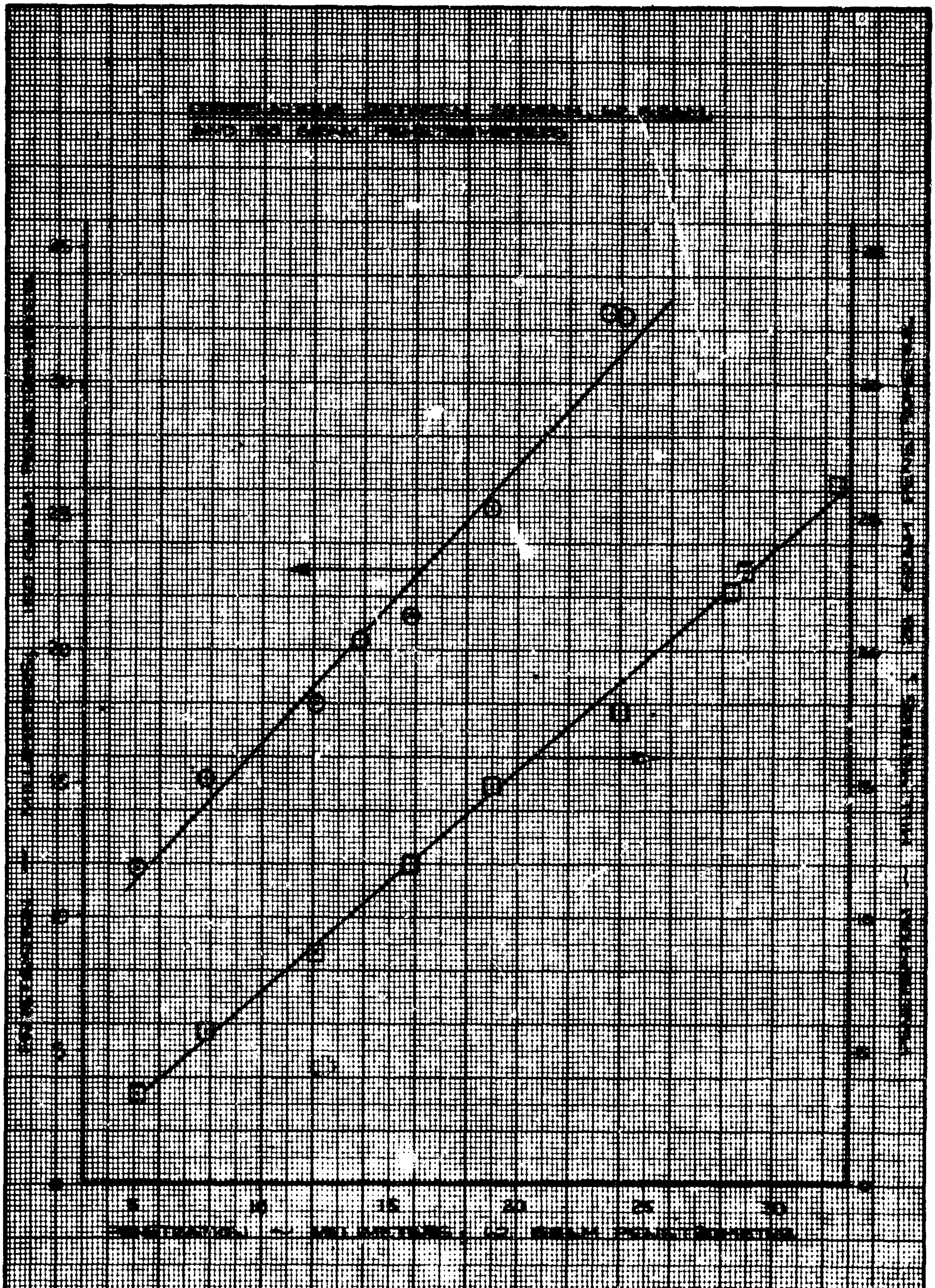

CALC	BURK	6/1/67	REVISED	DATE	STIFFNESS TESTING OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 13
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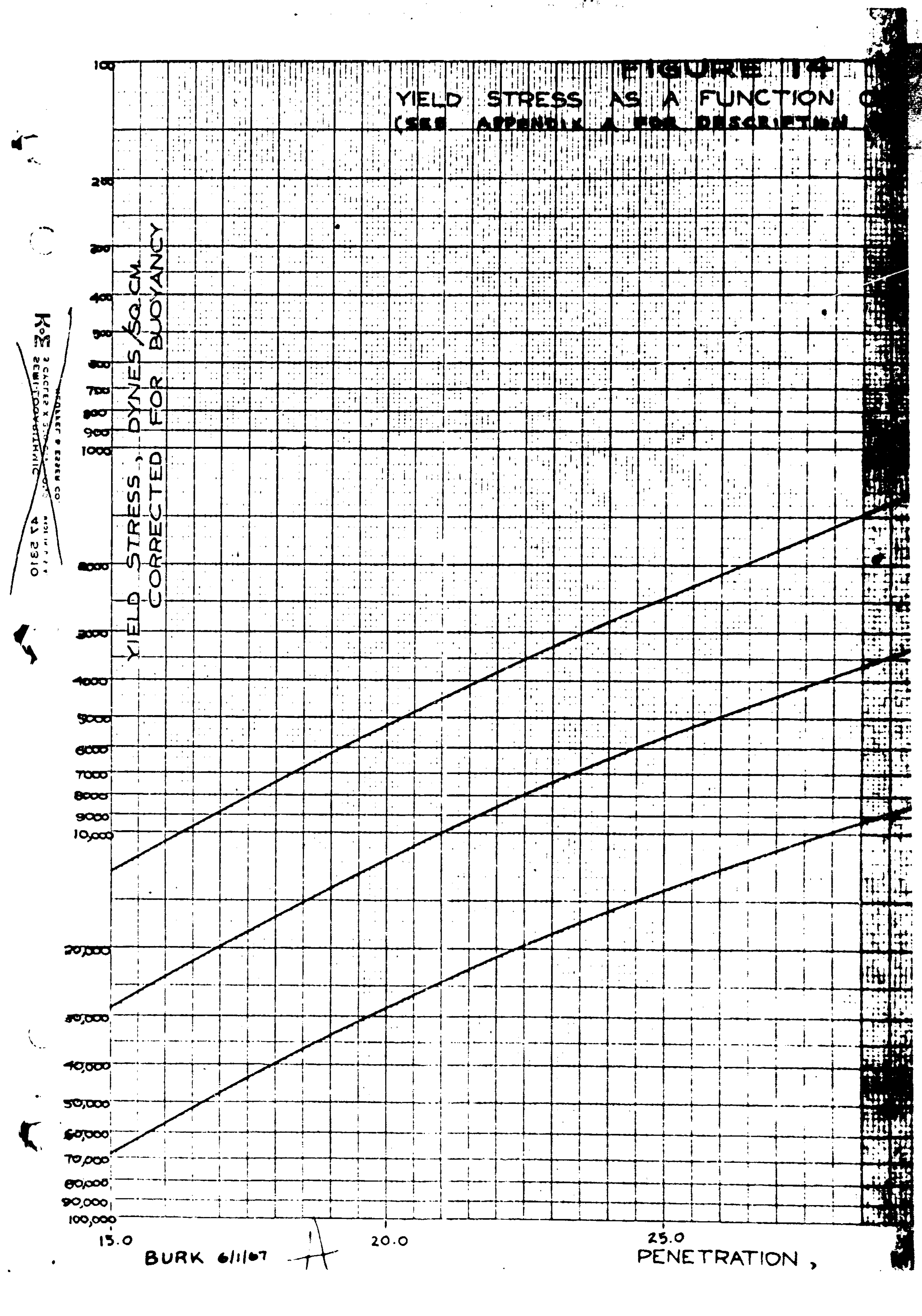
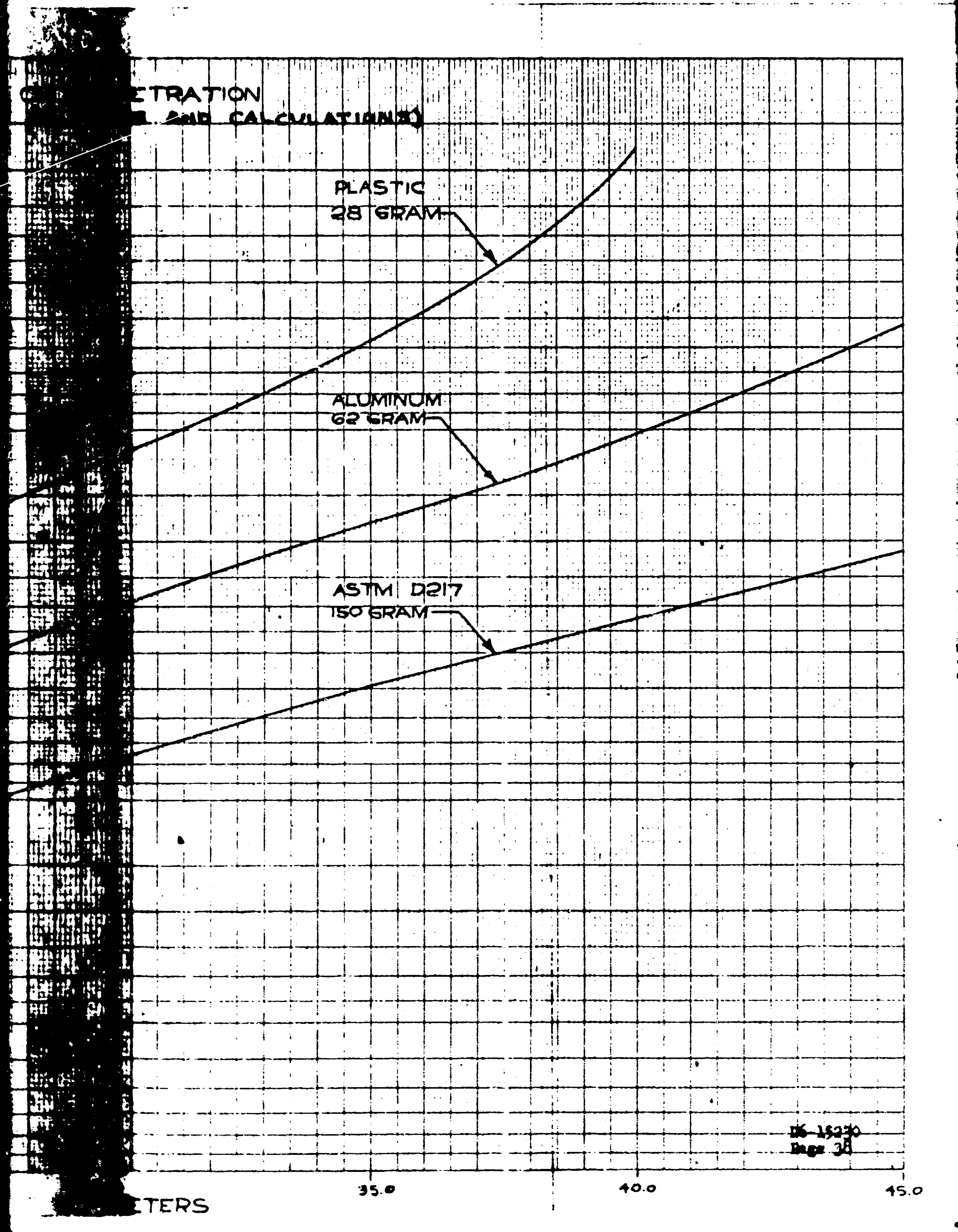


FIGURE 14
YIELD STRESS AS A FUNCTION O
(SEE APPENDIX A FOR DESCRIPTION
YIELD STRESS, DYNES/SQ.CM.
CORRECTED FOR BUOYANCY
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
15.0
20.0
25.0
PENETRATION ,
BURK 6/1/67

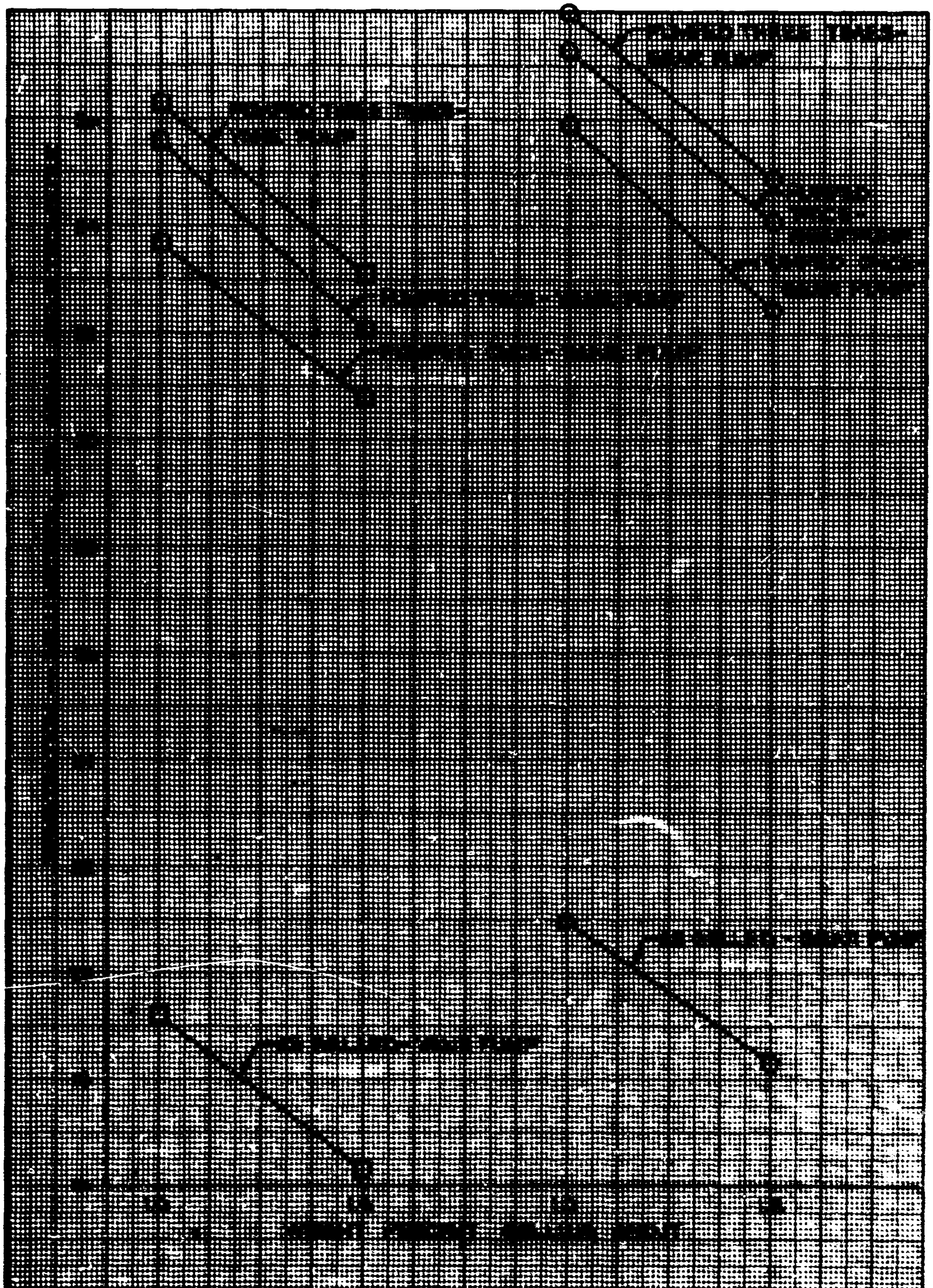

ETRATION
AND CALCULATIONS)
PLASTIC
28 GRAM
ALUMINUM
62 GRAM
ASTM D217
150 GRAM
35.0
40.0
45.0
TERS

and the naturally cooled gel had a penetration of 29.0, both being measured with the 62 gram cone. From all of this testing, it is obvious that in order to produce gels of constant consistencies the gellation procedure must be standardized in temperature, time and moisture control.

A correlation between the penetration of the three different weight penetrometer cones is shown in Fig. 13. Further correlation between penetration and yield stress can be arrived at theoretically if we assume that the yield stress is equal to the cone weight divided by the wetted area (see Appendix A). Yield stress as a function of penetration is shown in Fig. 14 for the three cones.

Since fuel is pumped one or more times before it is used in the engine, 0.5, 1.0, and 1.5 percent gels were pumped from one to six times with each of the following pumps: small vane pump; small gear pump; small centrifugal pump; large gear pump; and centrifugal boost pump. The effects of pumping upon the penetration levels and viscosities of the various gels are shown in Figs. 15, 16, and 17. For comparison the viscosity of liquid kerosene is 2 centipoise at 77°F.

Some of the pumped gels were stiff enough to measure with the penetrometer and fluid enough to measure with the Saybolt viscometer and the correlation shown in Fig. 18 was obtained from these data. This correlation is valid only for this gel and should not be used to evaluate any other fluid. The measurement of viscosity is a dynamic one associated with the flow of a fluid but penetration is a static measurement associated with a no flow condition. Note that the lowest viscosity reading of about 900 centipoises corresponds to a penetration of 39.0 millimeters with the 23 gram cone.



CALC	BURK	4/1/67	REVISED	DATE	EFFECT OF PUMPS ON CONSISTENCY OF KEROSENE GELS MADE WITH FAA 1065-1 GELLING AGENT	FIGURE 15
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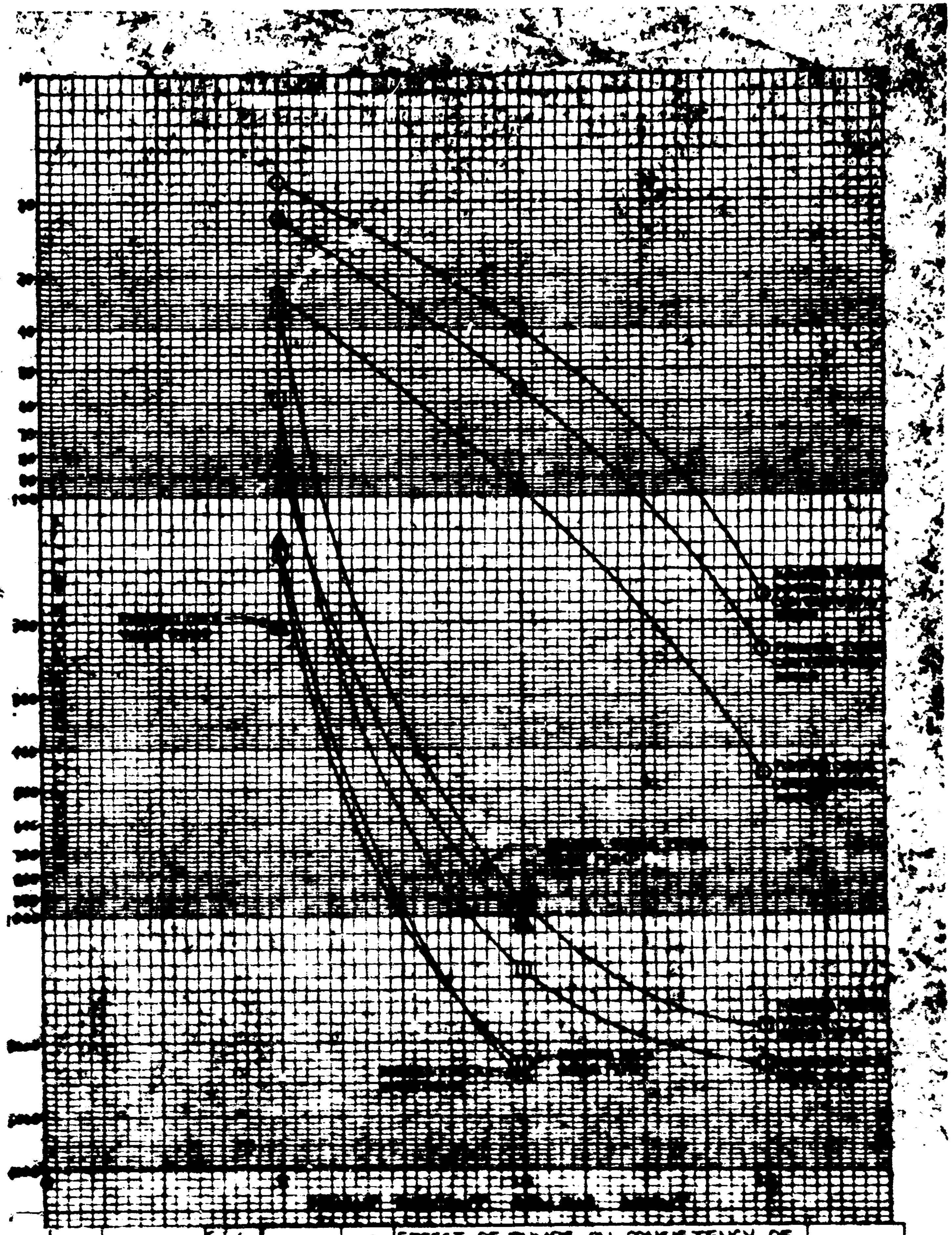

A/C	BURK	5/1/67	REVISED	DATE	EFFECT OF PUMPS ON CONSISTENCY OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 16
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APR					THE BOEING COMPANY	PAGE 41
APR						

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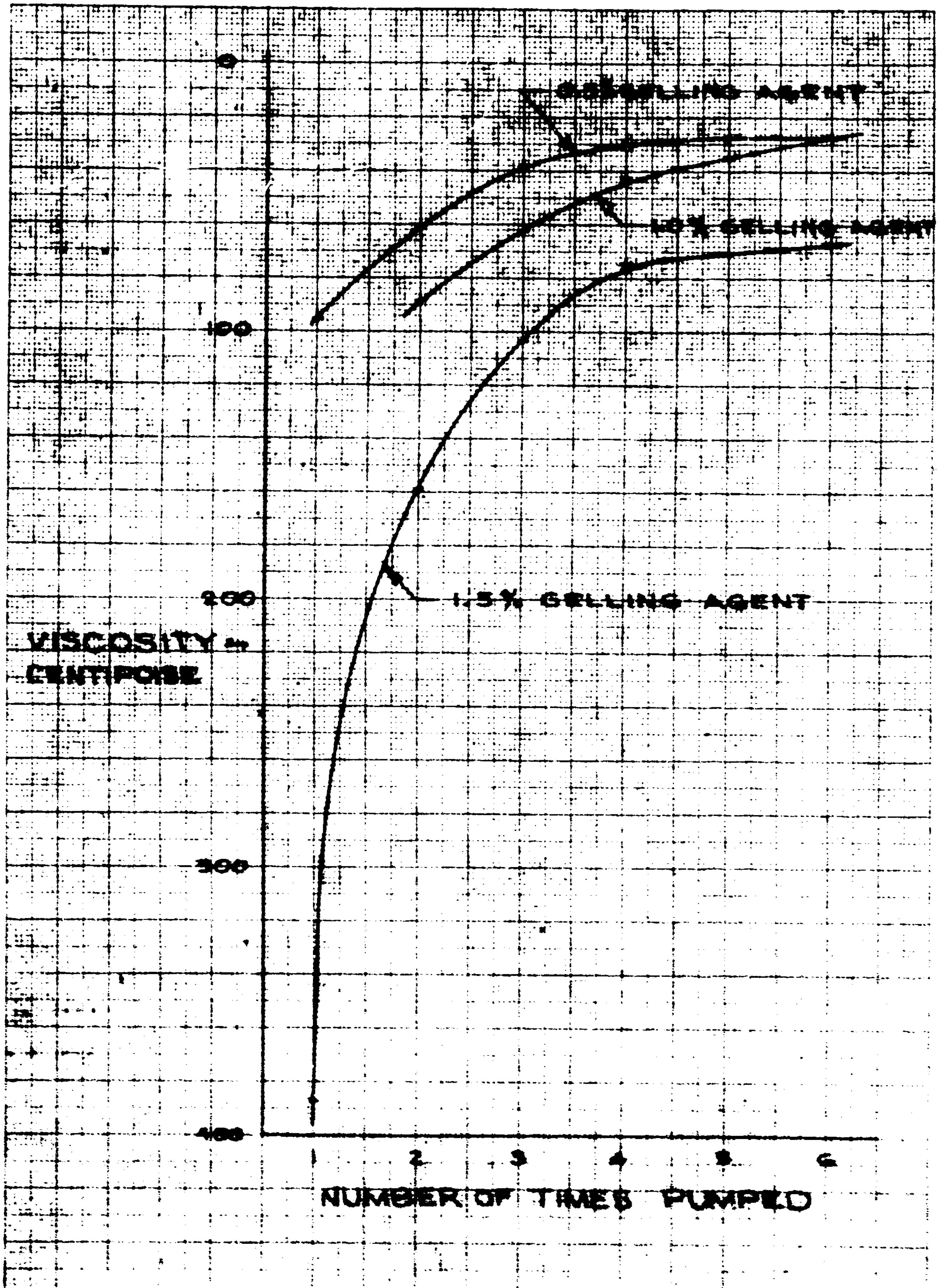
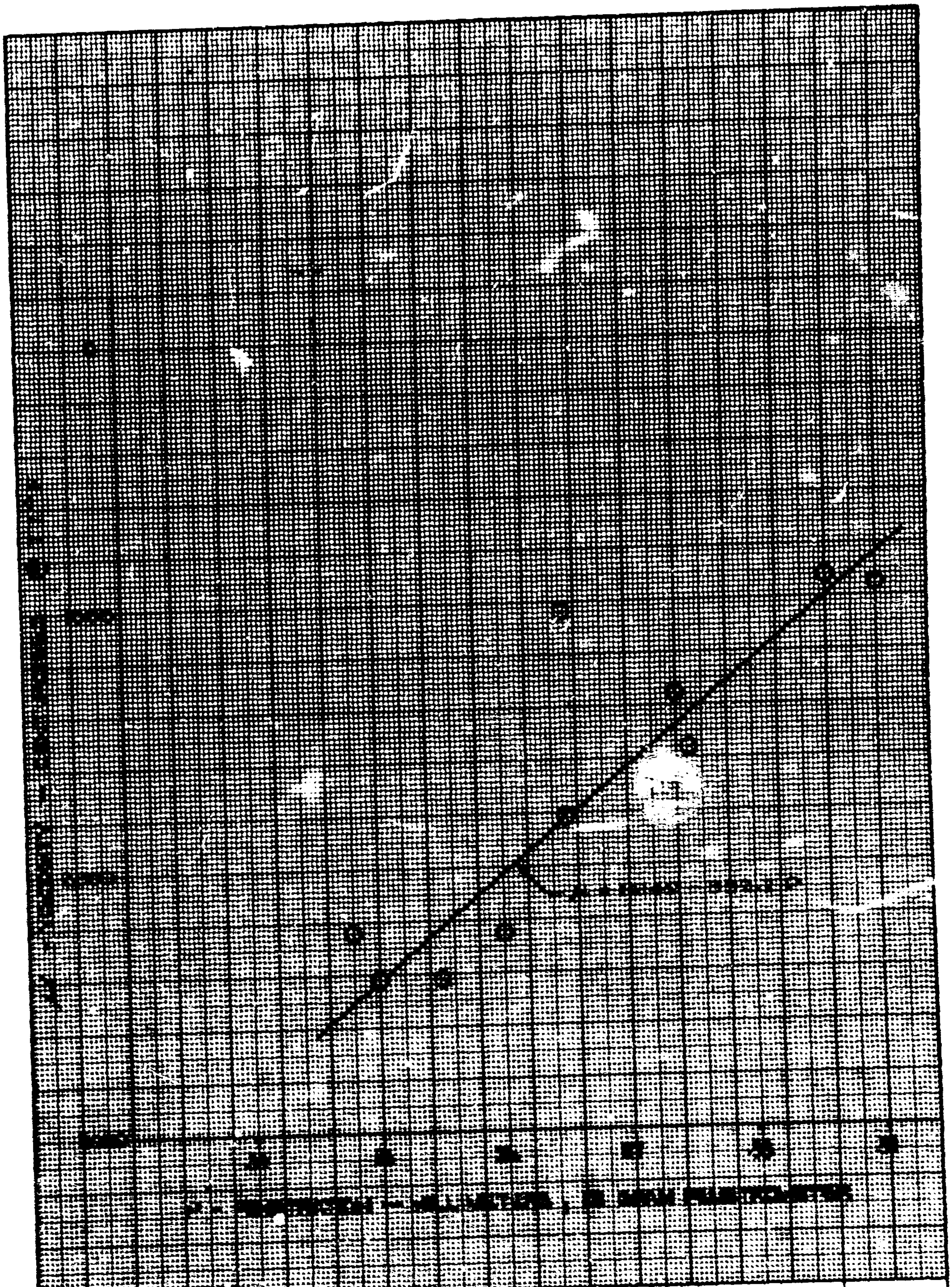


CALC	BURK	7/9/63	REVISED	DATE	EFFECT OF CENTRIFUGAL PUMP ON CONSISTENCY OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 17
CHECK						D6-15230
APR					THE BOEING COMPANY	PAGE 42
APR						



CALC	BURK	10/1/67	REVISED	DATE	CORRELATION BETWEEN VISCOSITY AND PENETRATION OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT
CHECK					FIGURE 18
APR					
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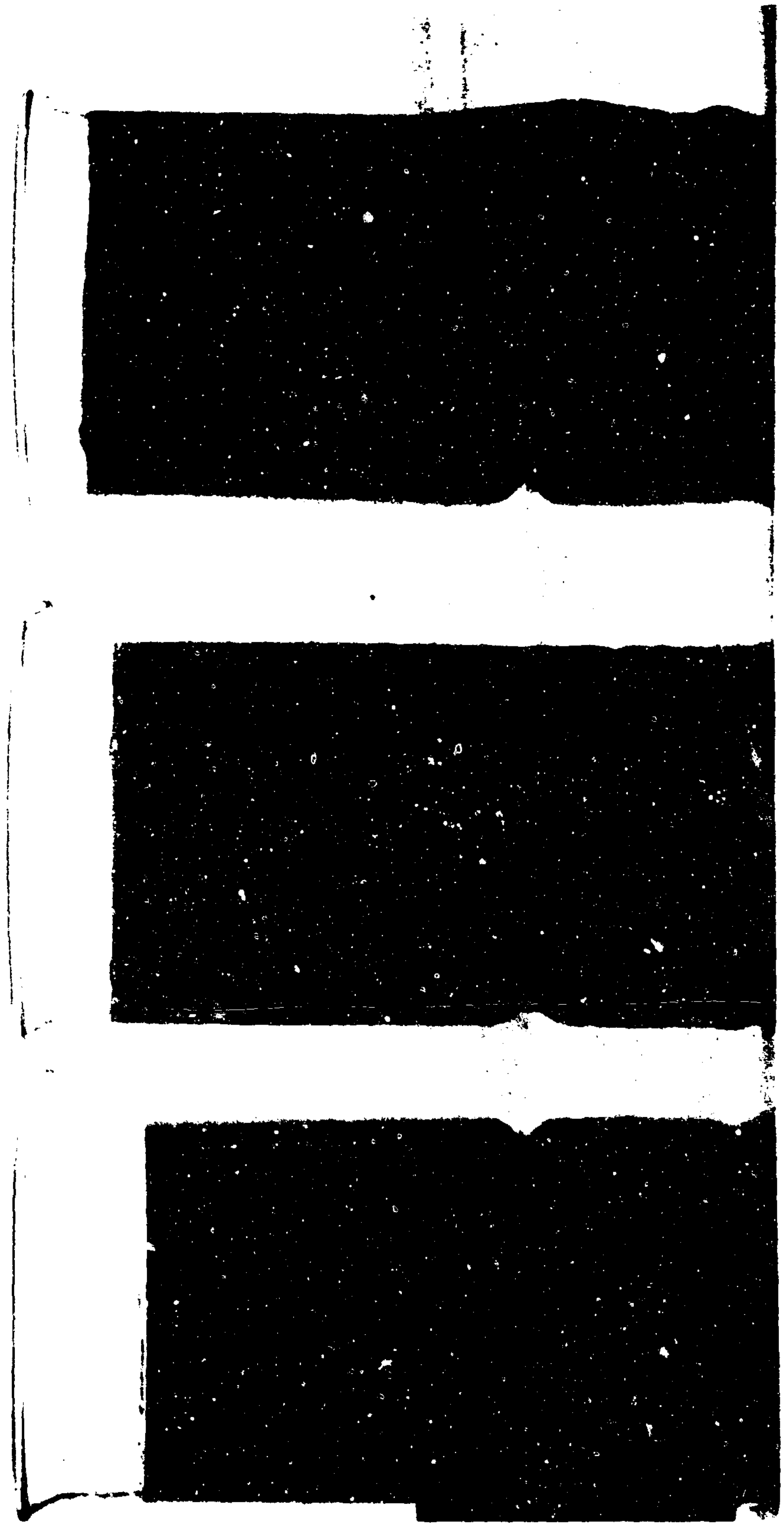
The vane pump works the gels slightly less than the gear pump while the centrifugal pump works the gels much more than the gear and vane pumps. As the number of times pumped with each of the different pumps increases, the effect upon the viscosity of the gel of each subsequent pumping is less until finally the gel has reached a level upon which further pumping has no effect. This level is usually attained by the time the gel has been pumped six times.

As shown in Figure 19, pumping aerated the fuel. The centrifugal pump aerated the fuel more than the gear pump. The effects of being pumped four times with a centrifugal pump are shown in Figure 20. The picture was taken one week after the three different strength gels were pumped. The lower layer is liquid fuel which has separated from the greatly aerated upper layer. The action of pumping not only reduces the stiffness of the gel, it also [illegible] the gel structure allowing liquid fuel to bleed out. This action produces a mixture displaying the same vapor pressure as the liquid fuel itself. In the as gelled condition the gel has been shown by others to require several hours to exert a vapor pressure equivalent to that of the liquid fuel.

A one percent gel was pumped with the gear pump through a 150 micron filter to determine the effects of filtration upon the strength of the gel. The Saybolt viscosity of the gel which was pumped through the filter was about one-half the Saybolt viscosity of a sample of the same gel pumped with the gear pump but not through the filter.



CALC	BURK	6/1/67	REVISED	DATE	SAMPLES OF 1% KEROSENE GEL MADE WITH FAA 106A-1 GELLING AGENT BEFORE AND AFTER PUMPING	FIG. 19
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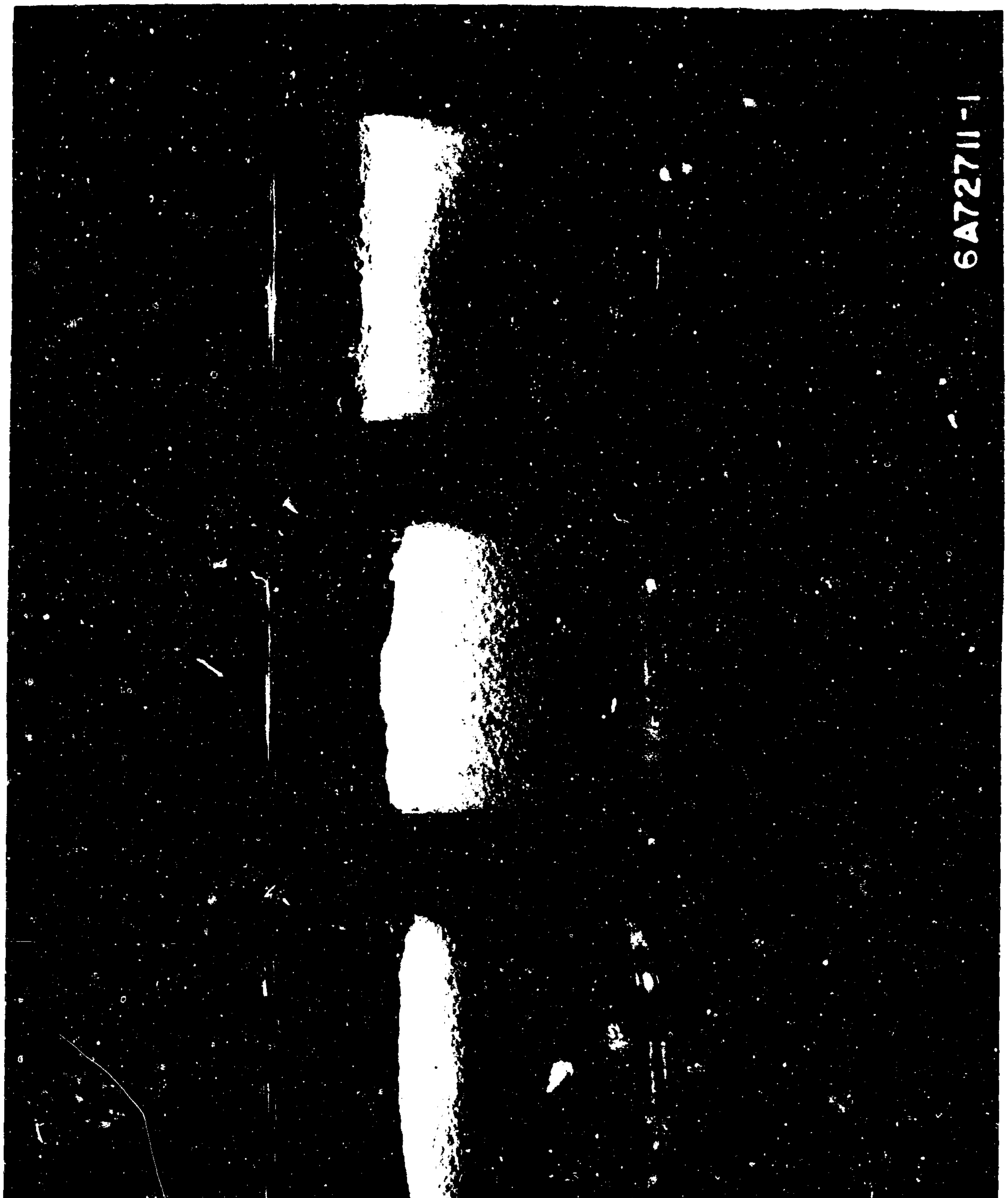

CALC	BURK	6/1/67	REVISED	DATE	SAMPLES OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT ONE WEEK AFTER BEING PUMPED FOUR TIMES WITH A CENTRIFUGAL PUMP	FIG. 20
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APPD						

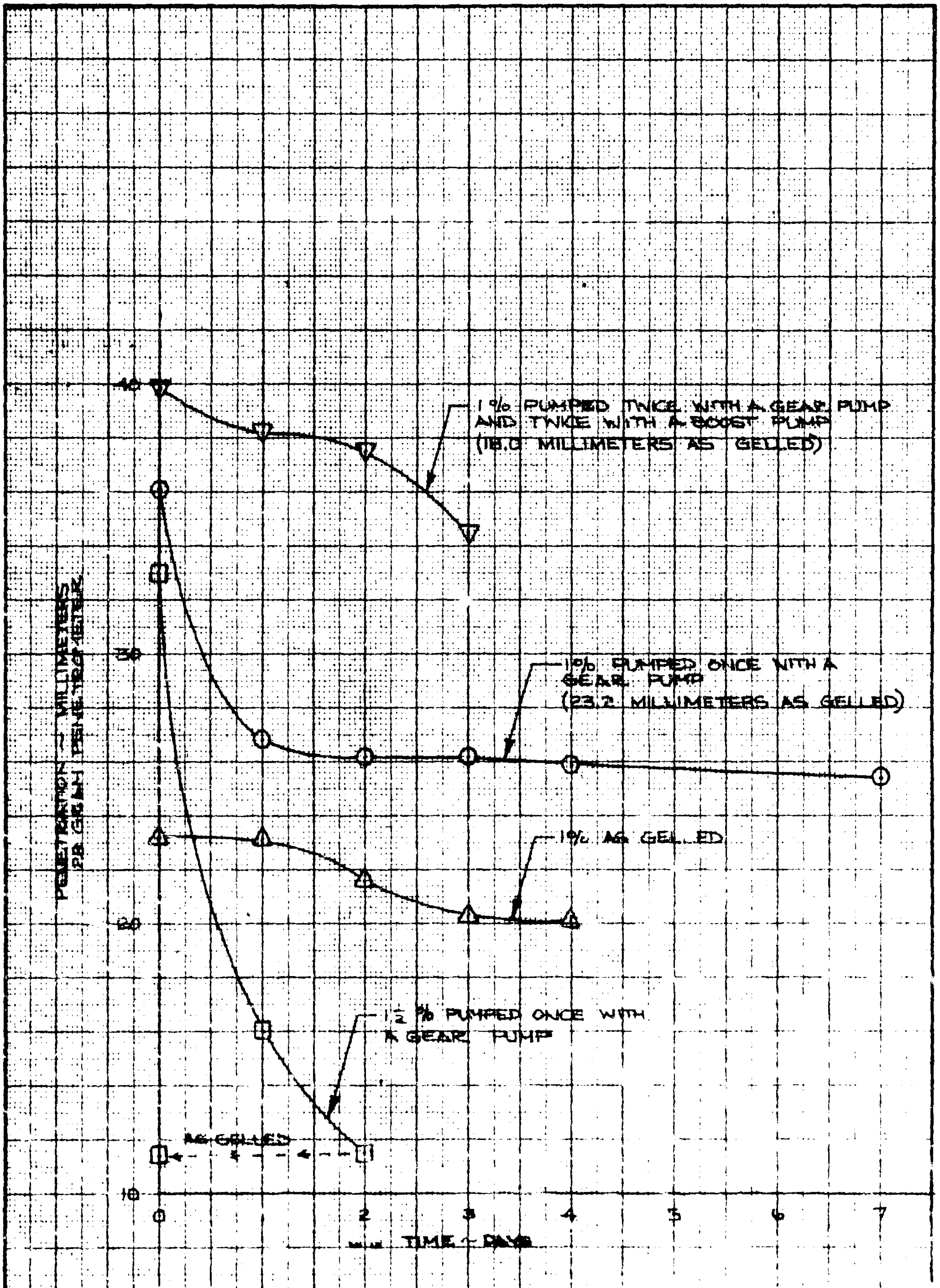
The results of the investigation of the time dependency of the stiffness and consistency of pumped and unpumped gels is shown in Figures 21 and [illegible]. An unpumped gel will slowly increase in stiffness day by day. Pumped gels however, exhibit a variety of rates and percentages of recovery depending on the degree to which they were pumped. The gels which were pumped only with a gear pump regained their "as gelled" stiffness in from two days to three weeks. Being pumped with the centrifugal boost pump seemed to break the gels to such an extent that they were unable to regain their original strength.

The effects of temperature upon the stiffness of both pumped and unpumped gels is shown in Figure 23. There is a continual increase in the stiffness of the gel as the temperature is lowered from 115 to -45°F. At temperatures below -45°F, the kerosene might start to freeze. At temperatures greater than 115°F, the gels liquefy and their viscosity is then the same as the liquid fuel from which they were made.

A one percent gel was made with kerosene to which had been added 20 milligrams of Arizona Road Dust per gallon of fuel. This had no effect upon the stiffness level of the gel. The Arizona Road Dust would settle to the bottom of the container as soon as stirring of the hot liquid gelled fuel was stopped.

b. Corrosion

The testing for corrosion characteristics of gelled fuel with aluminum, cadmium plated steel, magnesium and steel resulted in the cadmium plated steel being the only one significantly affected. There was a darkening of the metal surface but no pitting occurred for the cadmium plated



CALC	BURK	6/1/67	REVISED	DATE	EFFECT OF TIME ON CONSISTENCY OF KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 21
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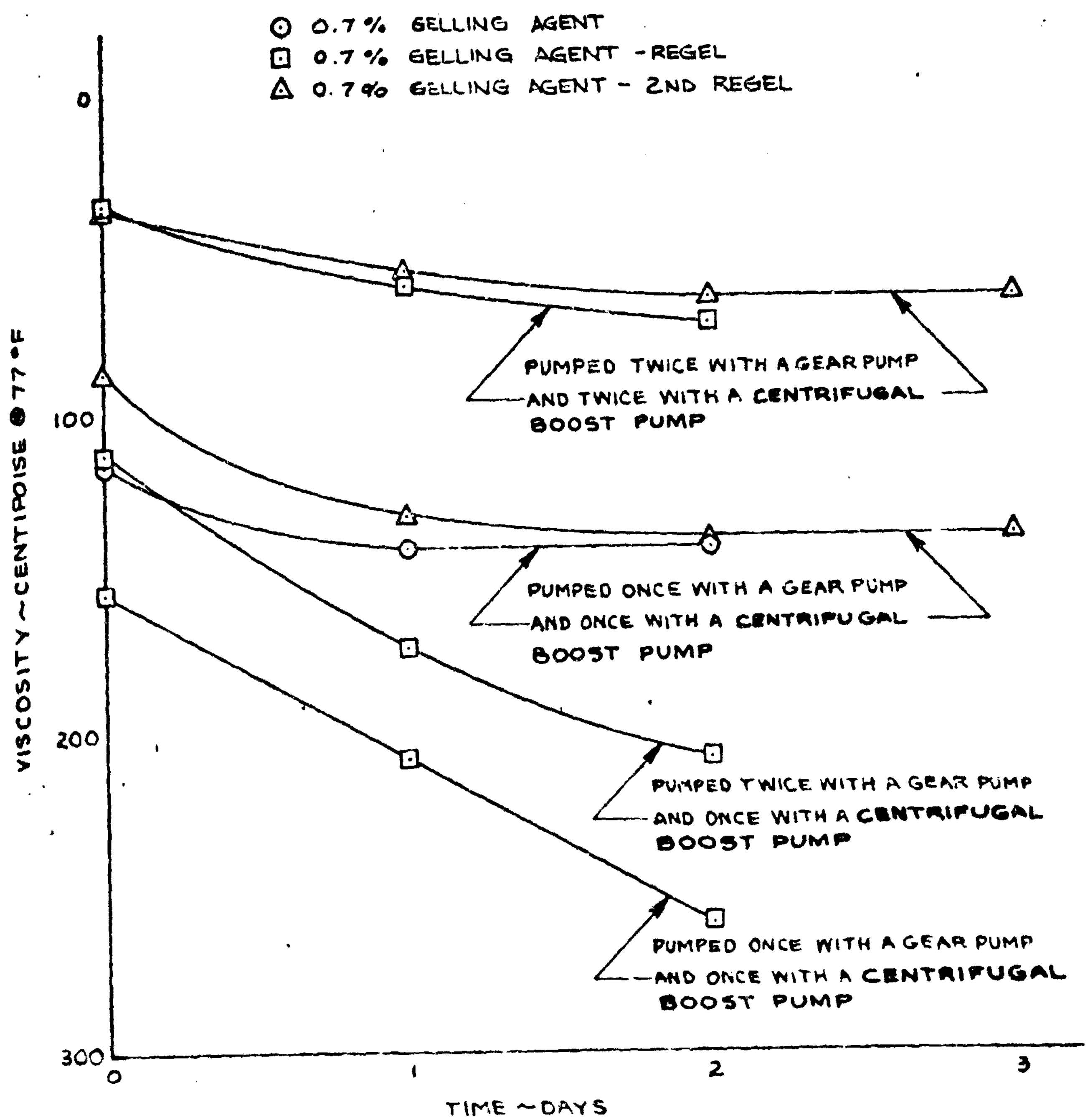

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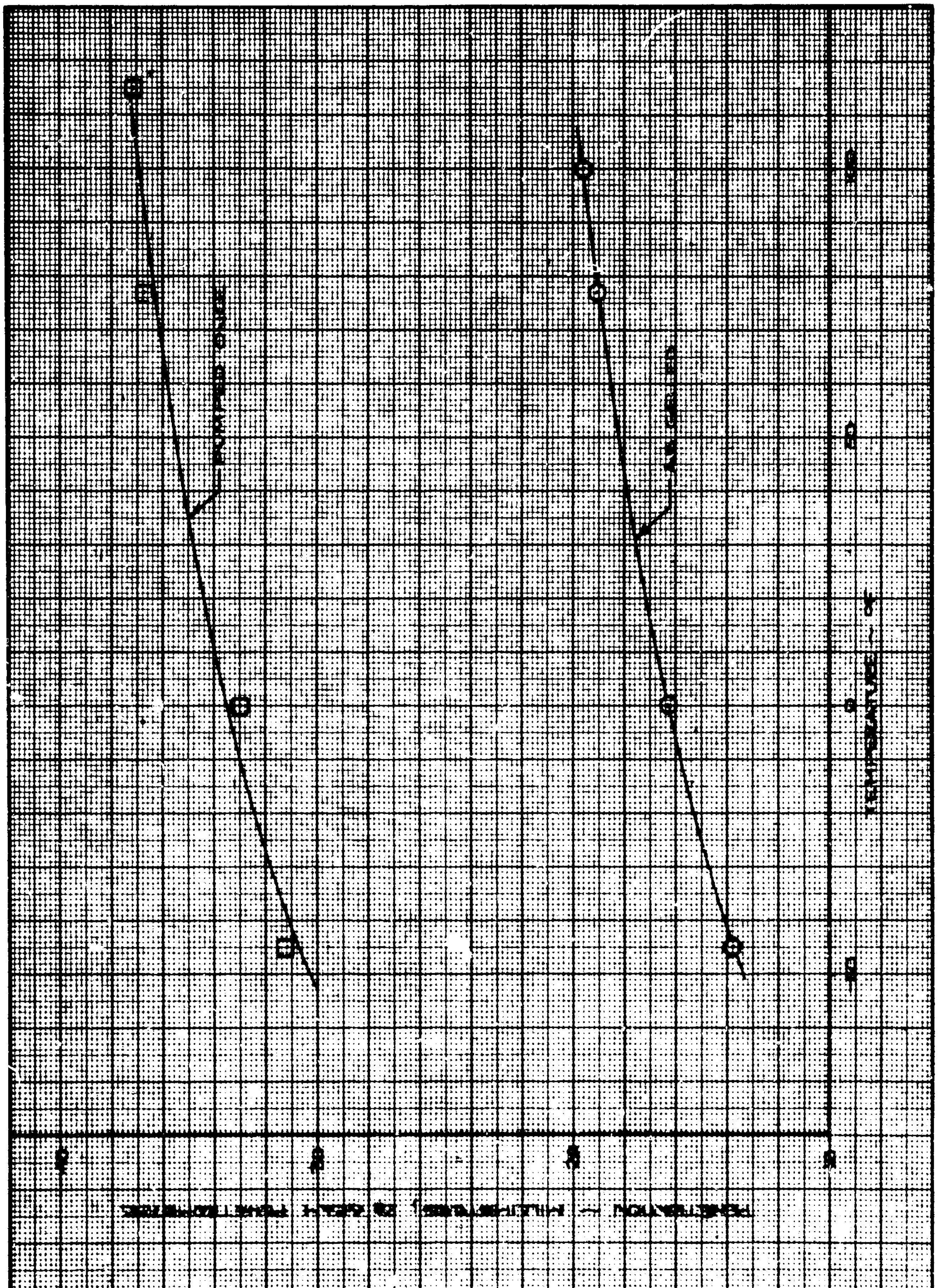
EFFECT OF TIME ON CONSISTENCY OF PUMPED KEROSENE GELS MADE WITH FAA 1069-1 GELLING AGENT

FIGURE 22



CALC	BURK	6/1/67	REVISED	DATE	EFFECT OF TEMPERATURE ON THE CONSISTENCY OF A 1% KEROSENE GEL MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 23
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APR					THE BOEING COMPANY	PAGE 50
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steel immersed in the gel. When the metal was suspended so that half was immersed in the gel and the other half extended into the atmosphere above the gel, there was a black line at the interface but no visible change on the part in the atmosphere. The tests were repeated using liquid kerosene and there was only a slight darkening of the surface with no measurable weight change.

c. Microbic Growth

In the micro-organism growth testing, the gelled fuel has slight to moderate growth of aspergillus flavus, aspergillus niger and penicillium citrium while the agar--fuel mixtures had only slight growth of these same three fungi. The kerosene had very slight growth of chaetomium globosum and penicillium citrium but with the addition of 0.5 per cent water to the kerosene, there was strong growth of aspergillus flavus, aspergillus niger, chaetomium globasum and penicillium citrium. Neither the agar and water nor gelling agent and water would support the growth of any of the fungi. From the data obtained in these tests, there is no evidence that the gelling agent will support fungus growth by itself. But neither will it inhibit that growth which can be found in a fuel-water mixture.

d. Teflon Coatings

There was very little difference in the ability of unpumped gel to flow down an aluminum or Teflon coated surface as determined by our limited testing. When both surfaces were dry, th Teflon coated surface had a little advantage over the bare aluminum surface. however, in time the gelled fuel did wet the Teflon as well as the aluminum surface eliminating this advantage. Small sections of gel, placed at one end of either pan, began to move when the pan was tipped

three to five degrees. Rate of movement was approximately 0.12 inches per second. The gel sections would not flow through the limber holes in either pan until the pans had been tipped up 45 degrees.

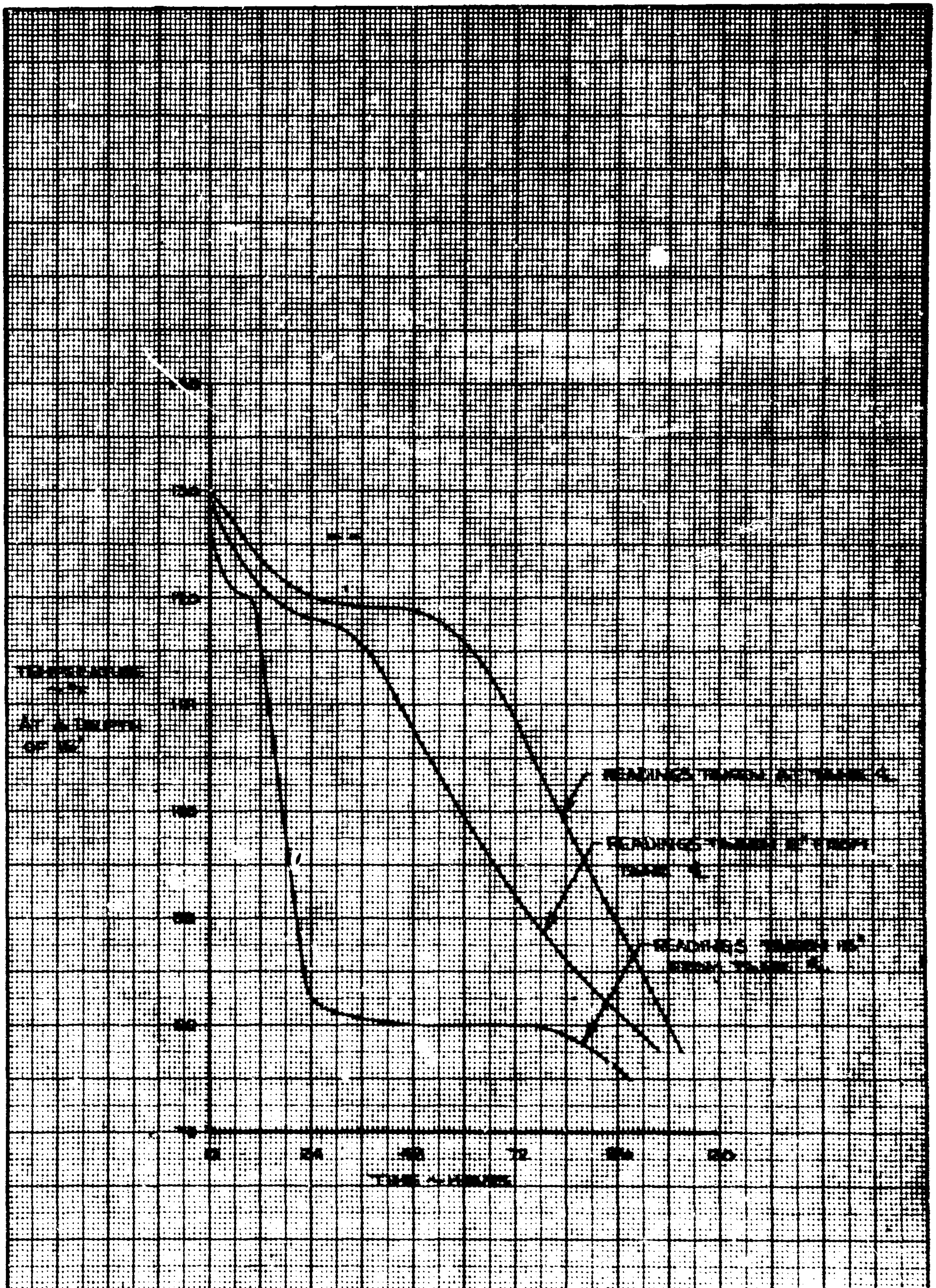
e. Cooling During Gellation

In making up the batches of gel in the large mixing tank, it was found that it took a long time for the gelled fuel to reach a uniform room temperature. The cool-down curve in Figure 24 for a typical 94 gallon batch shows that at least four days were required to reach room temperature throughout the batch. The top and sides seem to cool and gel first, and then this gel acts as an insulator in keeping the middle of the tank warm.

2. <u>Large Scale Tests</u>

a. Pumpdown

The 707 auxiliary boost pump with vapor eliminator and a snorkel type inlet was able to pump all of the approximately 100 gallons of the one percent pumped-once gel out of the pumpdown tank at sea level pressure. When about 100 gallons of a once-pumped gel were taken to a simulated altitude of 42,000 feet (2.4 psia) in steps, there were surface eruptions as air escaped from the gel, but very little volume increase occurred until the tank was at 42,000 feet. After about 30 minutes at this simulated altitude, the volume of gel had increased about five percent. Another 15 minutes resulted in this volume increase decreasing about 30 percent as more air escaped from the gel. When an attempt was made to pump the gel out of the tank while maintaining this simulated altitude, a flow rate of seven gallons per minute was obtained initially but this lasted only a short time with 35 of the 100 gallons [illegible] pumped out. This left about 65 gallons of gel having a head of 2. [illegible] over the pump inlet in the tank. Reducing the simulated altitude [illegible] 35,000 feet (3.4 psia) and then to 28,000 feet (4.88 psia) resulted in small amounts of this remaining gel being pumped out of



CALC	BURK	6/1/67	REVISED	DATE	COOLING CURVE FOR A 94 GALLON BATCH OF 1% KEROSENE GEL MADE WITH FAA 1069-1 GELLING AGENT	FIGURE 24
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APR						

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the tank at very low flow rates. During this part of the test, the flow was insufficient to keep the lines full of fuel as observed in the section of plastic tubing upstream of the boost pump. A final reduction to a simulated altitude of 18,000 feet (7.33 psia) alleviated the virtual no-flow condition and the remainder of the gel was pumped out at about 16 gallons per minute.

b. Wing Tank Flowability

An extensive investigation was made of the flowability of gelled fuel in the simulated wing tank. Table II presents the different combinations of parameters which were investigated in this portion of the testing and the pertinent quantitative results. The flow rates as shown are for a steady flow condition before the pump lost suction. The amount of fuel left in the tank was then determined. The pictures in Figures 25 - 32 were taken at the time that the pump lost suction.

The height differential across the baffle rib is an indication of the amount of restriction which the baffle rib presents to the fuel. Prior to pumping, the liquid kerosene (Runs 1, 2, and 3) had zero height differential as would be expected. The 0.5 percent "as gelled" gel (Runs 4 and 5) also did not have any differential since it was pumped into the wing tank in the liquid state. The rest of the gels had a height differential ranging from 0.25 inches to 1.5 inches depending on the stiffness of the gel. This height differential is associated with the yield stress of the gel in that a certain force is required before the gel will flow through the baffle check valves. The tank was always filled at the end furthest from the pump so the lower level was always on the pump side of

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TABLE II

SUMMARY OF PARAMETERS OF TESTING IN WING TANK SECTION
(Shown Graphically in Figure 37)

Run No.	% Gel	Times Pumped	Angles of Inclination, Degrees: Fore and Aft	Angles of Inclination, Degrees: Lateral	Flow Rate, GPM	Fuel Remaining When Pump **Lost Suction** Gallons	Height Differential Across Baffle, In.: Prior to Pumping	Height Differential Across Baffle, In.: During Pumping	Consistency [3]: Penetration 28 Gram Cone Millimeters	Consistency [3]: **Viscosity** @77° Centipoise
1	[illegible]		4	6	44	2.[illegible]	[illegible]	7.[illegible]		2
2	[illegible]		4	3	3[illegible].2	[illegible]	[illegible]	1		2
3	[illegible]		2	3	31.[illegible]	3.[illegible]	[illegible]	1-1,[illegible]		2
4	[illegible]	[illegible]	2	3	----	[2]	[illegible]	-----	2[illegible].[illegible]	(7122)
5	[illegible]	[illegible]	[illegible]	10	----	[2]	[illegible]	-----	23.[illegible]	(7122)
6	[illegible]	1	4	[illegible]	3[illegible].4	17.5	1.5	3	35.[illegible]	(1238)
7	[illegible].7 Regel	1	4	[illegible]	29.[illegible]	14.2	1.5	3	36.5	(1827)
8	.7 Regel	3	4	3	14.[illegible]	12.3	.25	1.5	(40.9)	112
9	[illegible].7 2nd Regel	3	2	3	14.[illegible]	12.[illegible]	.25	1.[illegible]	(41.[illegible])	6
10	1.5 2nd Regel	1	4	6	14.4	2[illegible]	1.5	4 - [illegible]	33.[illegible]	(3199)
11	1.5 Regel [1]	1	[illegible]	[illegible]	----	[2]	----	-----	25.[illegible]	(6337)

[1] The gel was pumped into the tank and allowed to "sit" for four hours before the test began.

[2] **In these cases, very little fuel was pumped out; almost all of the 50 - 60 gallons of gel was left in the tank.** This can be seen in Figures 29, 30 and 32.

[3] **Values in parentheses are calculated for correlation purposes only by using the relation shown in Figure 18.**

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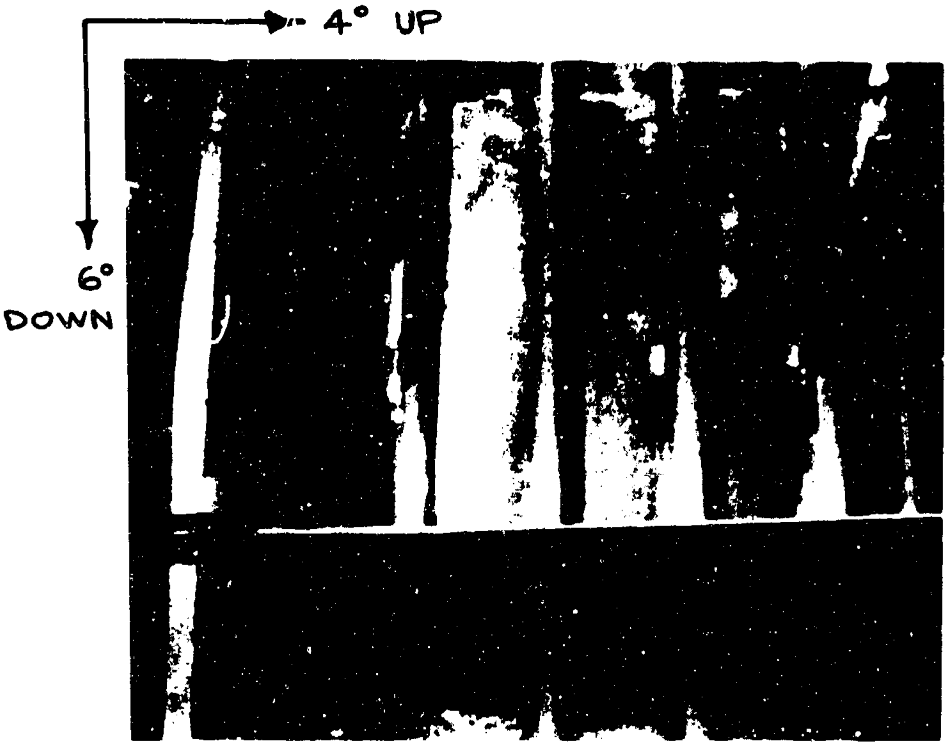

FIGURE 25
RUN NO. 1 - LIQUID KEROSENE AT END OF PUMPDOWN

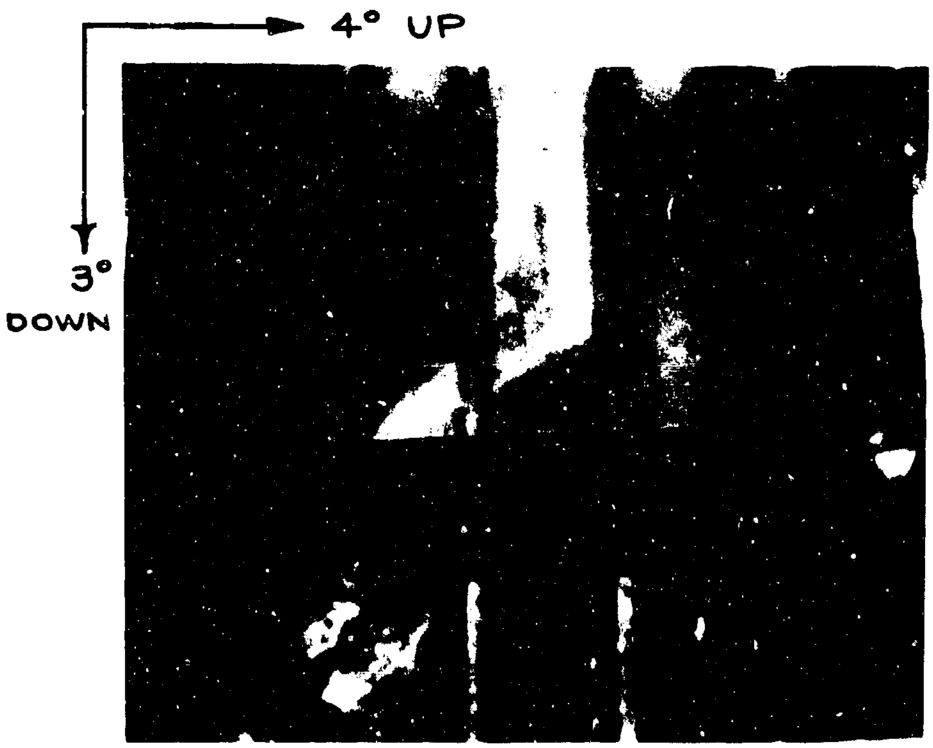

FIGURE 26
RUN NO. 8 - PUMPED THREE TIMES 0.7 % GEL
AT END OF PUMPDOWN

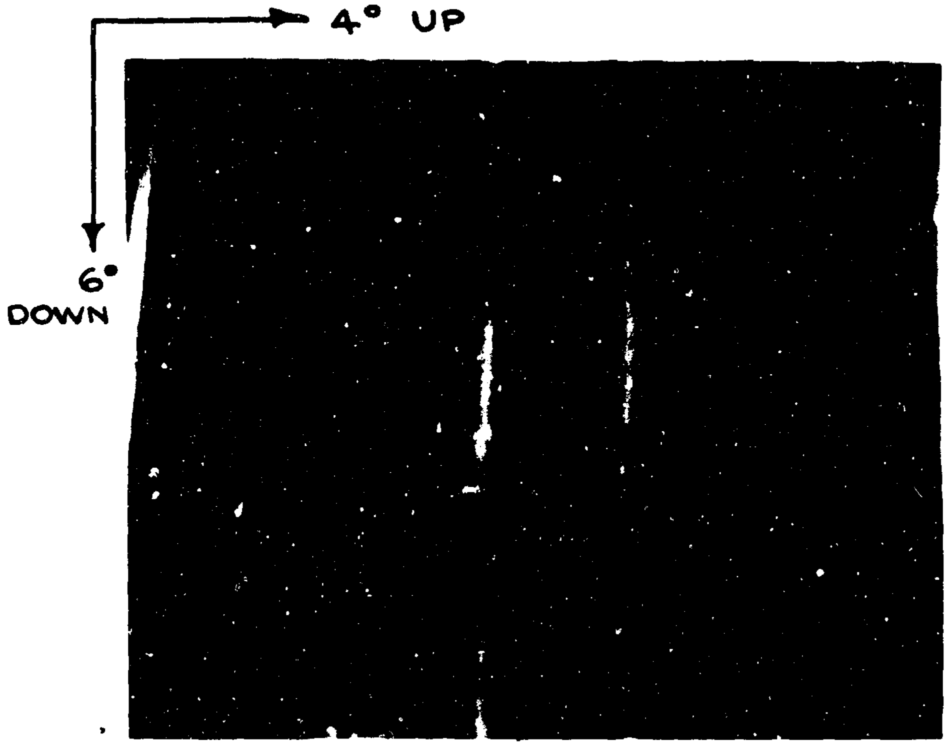

FIGURE 27
RUN NO. 7 - PUMPED ONCE 0.7% GEL AT END OF PUMPDOWN

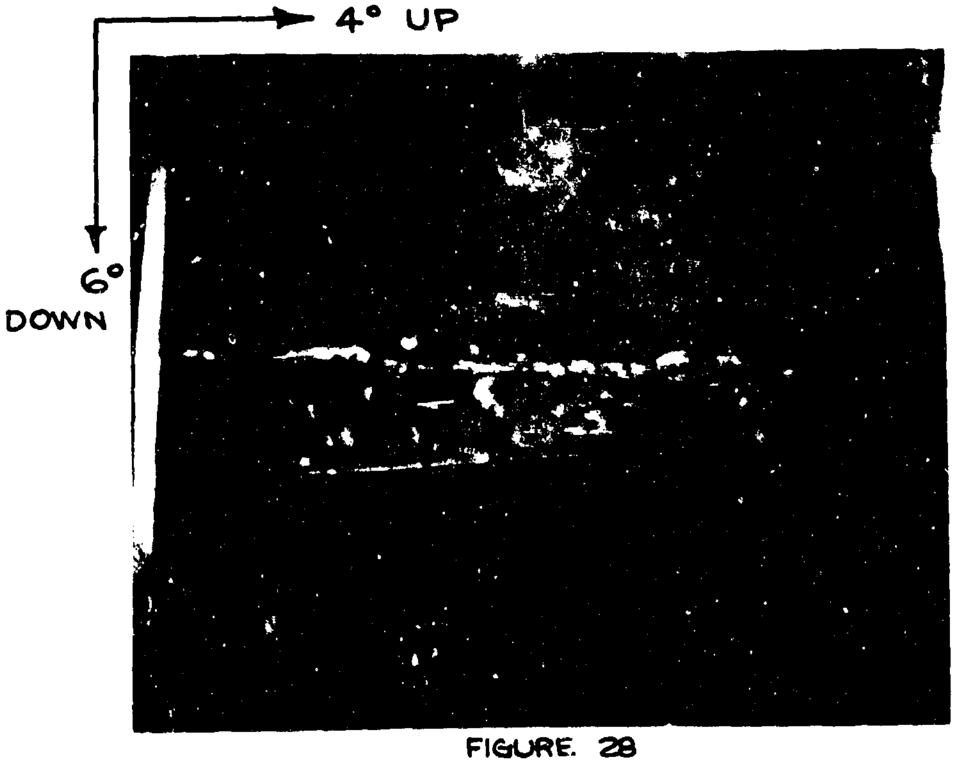

FIGURE 28
RUN NO. 6 - PUMPED ONCE 0.7% GEL AT END OF PUMPDOWN (STIFFENER ADJACENT TO PUMP INLET STILL IN PLACE)

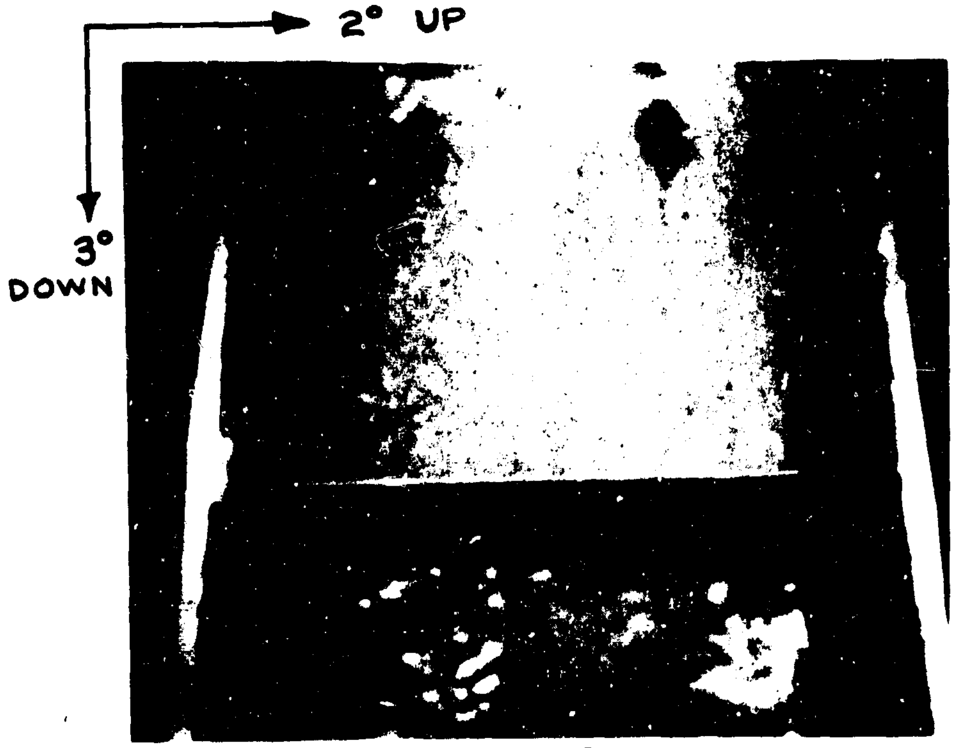

FIGURE 29

RUN NO. 4 - "AS GELLED" 0.5 % GEL AT END OF PUMPDOWN (TANK SET AT 2° AND 3°)

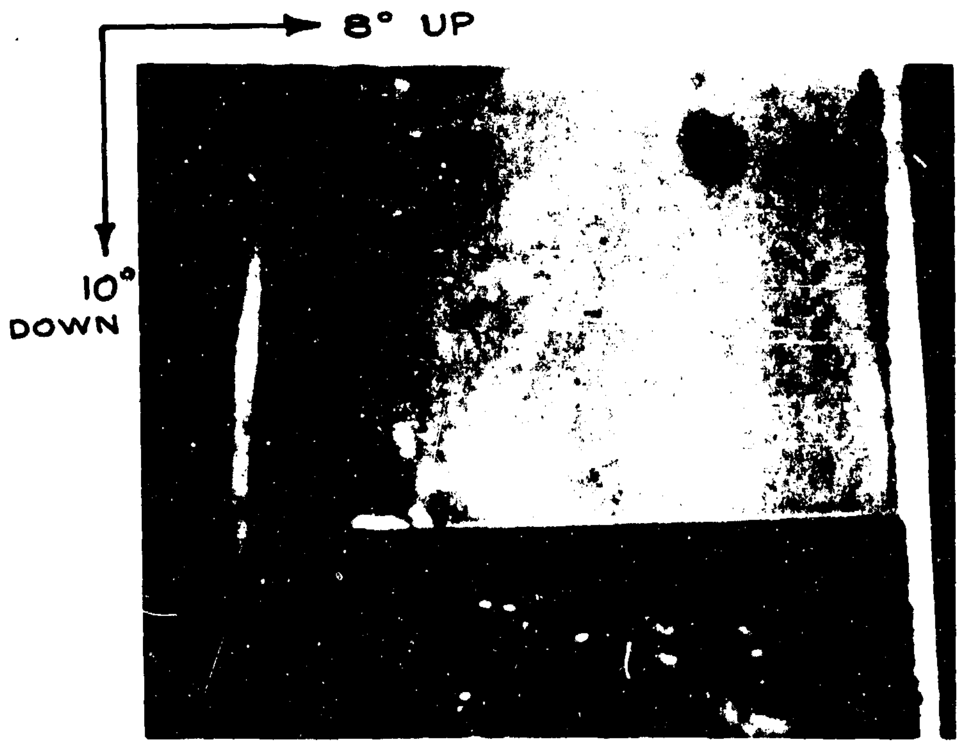

FIGURE 30

RUN NO. 5 - "AS GELLED" 0.5 % GEL AT END OF PUMPDOWN (TANK SET AT 8° AND 10°)

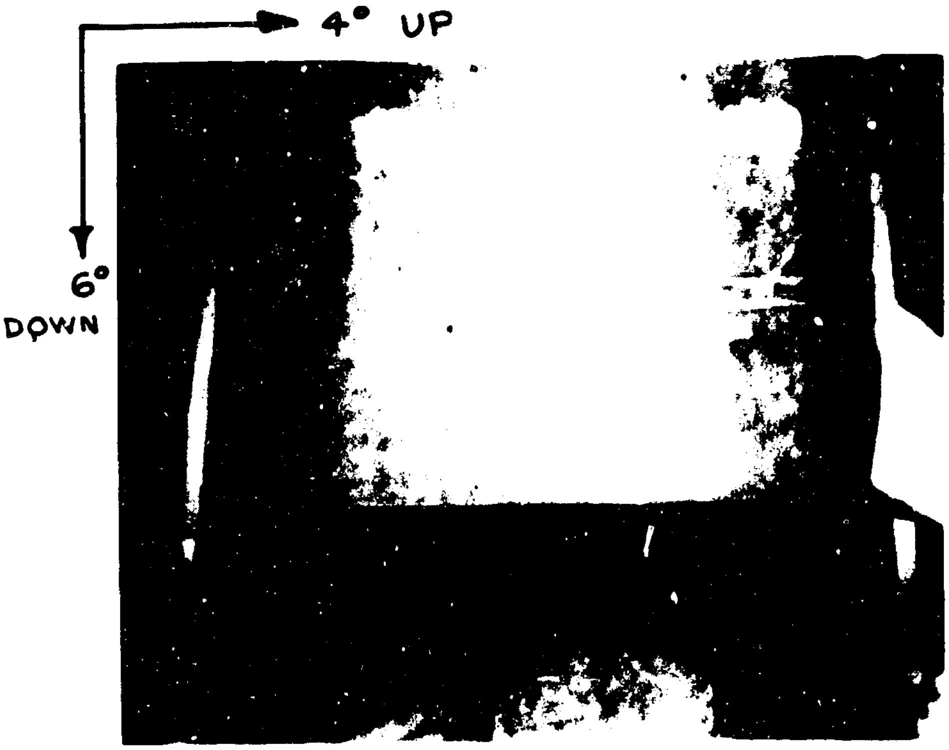

FIGURE 31

RUN NO. 10 - PUMPED ONCE 1.5 % GEL AT END OF PUMPDOWN

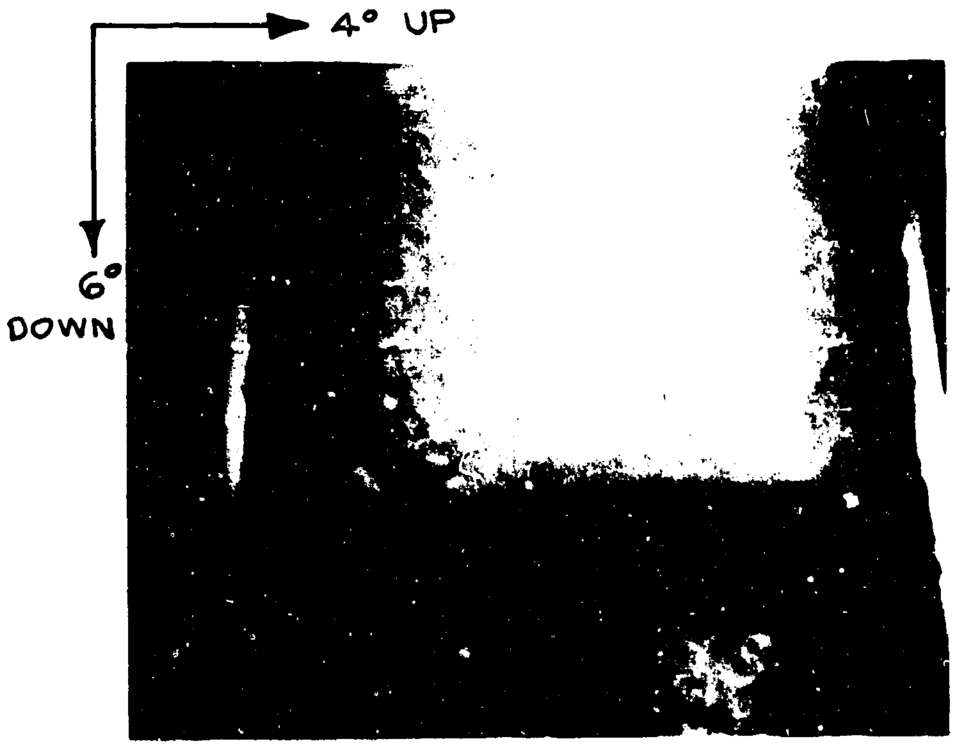

FIGURE 32

RUN NO. 11 - PUMPED ONCE 1.5 % GEL AFTER FOUR HOUR INTERVAL AT END OF PUMPDOWN

the baffle rib. During the pumping tests, these height differentials increased because of the pressure drop associated with the flow through the check valves at the rate of pumping. The greatest height differential occurred during pumping of the 1.5 percent gel (Run 10) which was the stiffest gel we were able to pump.

During the pumping tests, some observations were made of the remainder of fuel in the wing tank and of the fuel pumped out of the wing tank into the mixing tank. The "snake" of 1.5 percent gel shown in Fig. 33 was found in the wing tank after Run number 11. This is some unpumped gel which was gelled in a section of tubing downstream of the gear pump. The lump shown in Fig. 34 was after the same run and was found in the wing tank after letting the residual 1.5 percent gel remain there for 24 hours. Shown in Figs. 35 and 36 is a lump which was part of this 1.5 percent gel which had been pumped into wing tank (gear pump) and back to the mixing tank (centrifugal boost pump) and was left in the mixing tank for 24 hours. As can be seen in Fig. 37, only two of the various strength gels tested were fluid enough to have even marginal flow capability. The pumping tests showed that the 0.5 percent "as gelled" gel (Runs 4 and 5) was virtually unflowable and indicated that any "as gelled" gel which forms a self supporting structure will also be unflowable. The 1.5 percent gel (Run 11) which had set in the simulated wing tank for three to four hours before attempting to pump it out, was also considered unflowable. At a 28 gram cone penetration of 33.0 millimeters (Run 10) the gel begins to flow. At 36.5 to 38.0 millimeters penetration (Runs 6 and 7) flow is very slow. Gels of 60 and 112 centipoise viscosity (equivalent

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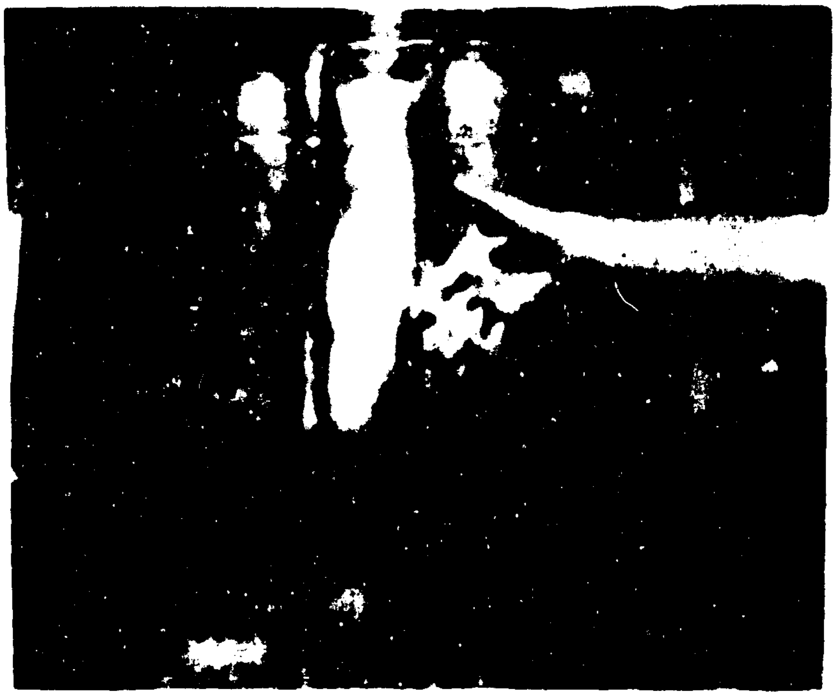


FIGURE 33

"SNAKE" OF 1.5% GEL FROM WING TANK

FIGURE 34

LUMP OF 1.5 % GEL FROM WING TANK

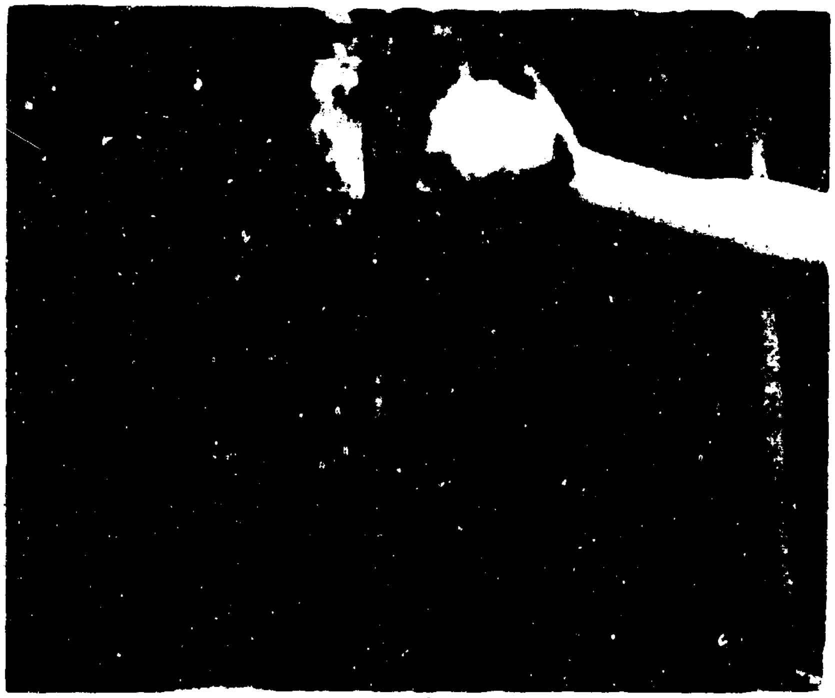


FIGURE 35
LUMP OF 1.5 % GEL FROM MIXING TANK

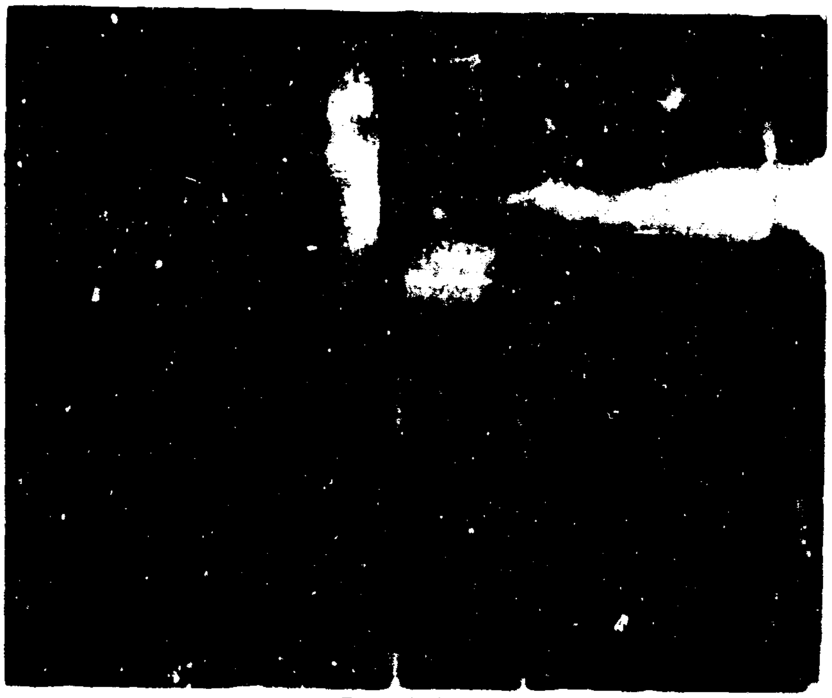
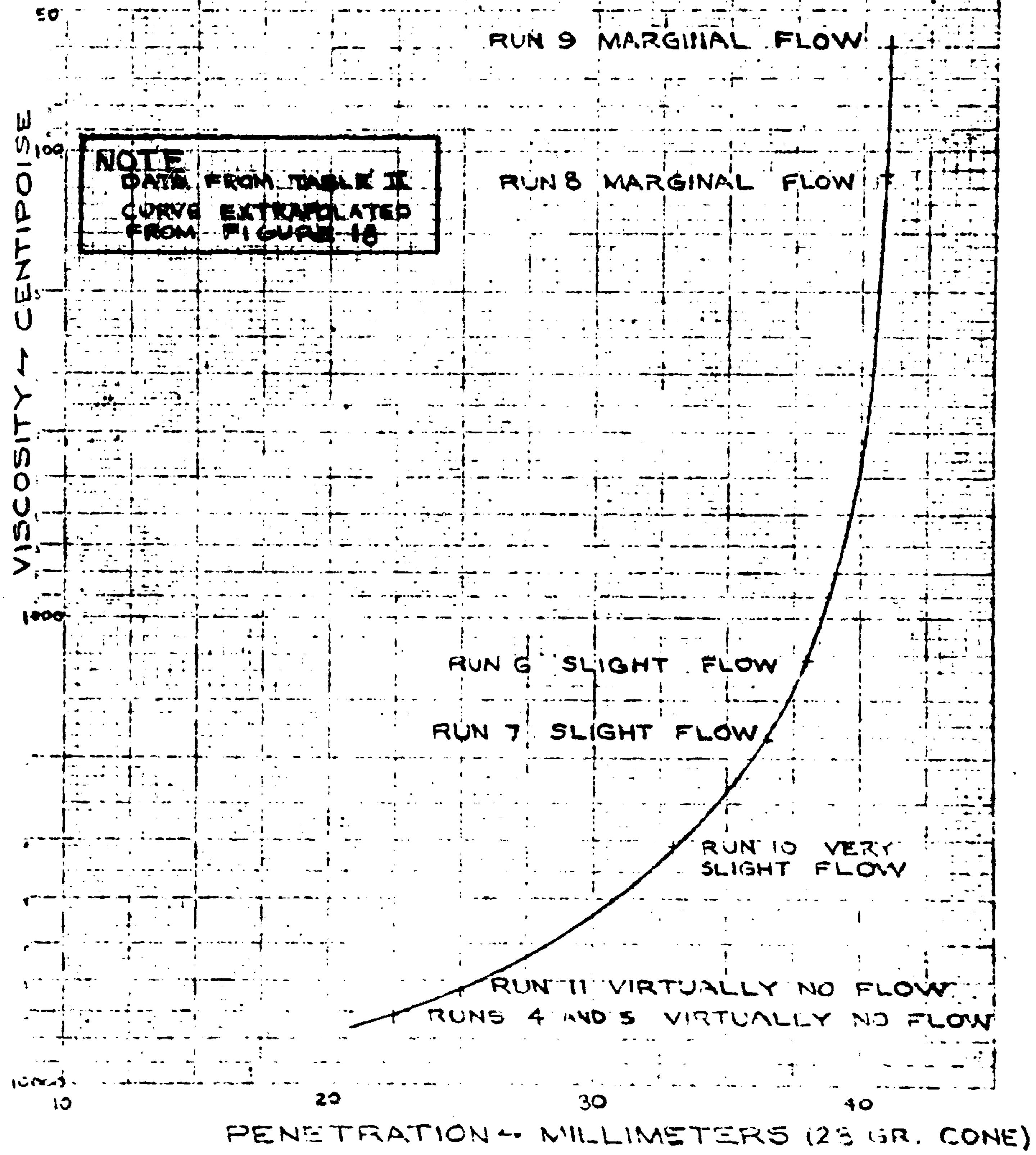


FIGURE 36
LUMP OF 1.5 % GEL FROM MIXING TANK



CALC	BURK	1/22/..	REVISED	DATE	PENETRATION AND VISCOSITY OF KEROSENE FUEL GELS USED IN WING TANK FLOWABILITY TESTING	FIGURE 37
CHECK						D6-15230
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to 40.9 and 41.0 millimeters penetration) flowed so as to be considered marginal for use in an airplane fuel system (Runs 8 and 9).

The gelled fuels which we have classified as being marginal were considered to be marginal in their capability to flow within the tank to the tank boost pump inlet. In our present aircraft fuel systems, we depend upon this gravity flow of the fuel to the tank boost pump inlet with a minimum amount of fuel remaining in the tank. With these marginal gels, considerable amounts remained in the tank when the tank boost pump lost suction.

In case of a tank boost pump or electrical power failure, our present fuel systems can also gravity feed liquid fuel through the airplane fuel system to the engine fuel pump inlet to at least 6,000 feet altitude. The marginal gels obviously do not have this capability of suction feed. In fact, due to increased pressure drop and flow restrictions, it is highly unlikely that any gel would be able to be gravity fed to the engine pump inlet.

c. Vibration

The vibration testing was done in three parts. The vibration spectrum for the two tests on the unpumped gel are shown in Table III.

There was little effect upon the unpumped gel until the double amplitude exceeded 1.5 inches. Initially, there was liquid on the surface of the gel. This has bled into the holes made when samples were removed for penetration testing. The vibration action caused a foaming of this liquid in the inboard section and sloshing of the gel in the center section. The movement of this center section of gel compacted it, creating gaps between

TABLE III

DATA FOR VIBRATION TESTING OF "AS GELLED" 1.0% GEL

Vibration Spectrum for First Test 1							
Length of Time	30 Sec	30 Sec	30 Sec	5 Min	1 Min	1 Min	3 Min
Double Amplitude, In.	.5	1.0	1.5	1.8	2.0	2.5	3.2
Frequency, CPS	3	3	3	3	3	3	3

1 At the time this test was run, 3.2 inches amplitude at 3 CPS was the maximum capability of the test Rig. An accumulator in the hydraulic line increased the capability to 5.4 inches amplitude at 3 CPS.

Vibration Spectrum for Second Test											
Length of Time	30 Sec	30 Sec	30 Sec	5 Min	1 Min	1 Min	3 Min	30 Sec	30 Sec	30 Sec	1 Min
Double Amplitude, In.	0.5	1.0	1.5	1.8	2.0	3.0	3.6	4.0	4.5	5.0	5.4
Frequency, CPS	3	3	3	3	3	3	3	3	3	3	3

the gel and the ribs. The movement of the gel also induced bleeding of liquid fuel at the bottom of the tank, particularly where it had gelled around the stiffeners. This liquid was then forced from the bottom of the tank to the surface of the gel at the inboard face of the outboard rib. At the high end of the amplitude spectrum, the action was violent enough to cause some liquid fuel to be thrown out of the tank. Very little occurred in the outboard section of the tank section.

The reaction of the pumped gel to the vibration spectrum shown in Table IV, was much more violent than the reaction of the unpumped gel. Again, very little occurred in the low amplitude portion of the spectrum. As the double amplitude increased above 1.8 in., the motion of the gel increased. At the highest double amplitude used for the pumped gel, 3.6 in., the action in the inboard section became so violent that gel was thrown out of the tank. Approximately ten gallons of gel were thrown out before the end of the test. As gel was thrown out of the inboard section, more gel would flow into this section through the flapper check valves. This violent splashing of the pumped gel occurred only in the inboard section. This was attributed to the geometrical differences in the three sections of the tank. The pumped gel had a slight increase in penetration level at the end of the vibration testing. If the wing tank had been covered and the period of vibration was extended for some time, the motion of the gel would tend to liquify it even more.

TABLE IV

DATA FOR VIBRATION TESTING OF FUMED [illegible] GEL

	Vibration Spectrum						
Length of Time	[illegible] Sec	3[illegible] Sec	30 Sec	[illegible].5 Min	30 Sec	[illegible] Sec	1.[illegible] Min
Double Amplitude, In.	[illegible].5	1.	1.5	1.[illegible]	[illegible].5	3.[illegible]	3.
Frequency, CPS	3	3	3	3	3	[illegible]	3

Penetration of Gel before vibration	[illegible] millimeters with 2[illegible] gram cone
Penetration of Gel after vibration	3[illegible] millimeters with 28 gram cone

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V. REFERENCES

1. Federal Aviation Agency Aircraft Development Service Report FAA-ADS-62, Feasibility Study of Turbine Fuel Gels for Reduction of Crash Fire Hazards, by Ken Posey, Jr., Dr. Richard Schleicher, et al, The Western Company, Dated February 1966

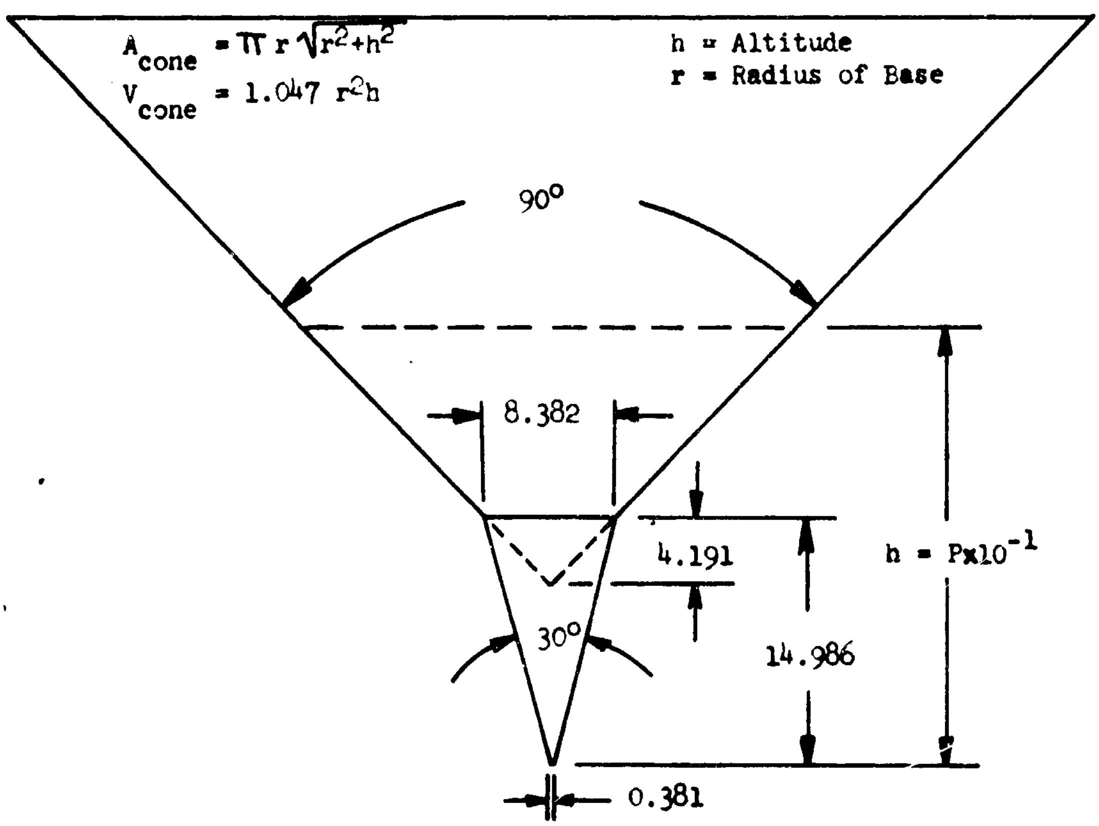
2. Boeing Test Report T6-5061, Gelled Fuel Investigation, Dated November 8, 1967

APPENDIX A

Calculations of Yield Stress as a Function of Penetration

CALCULATIONS OF YIELD STRESS AS A FUNCTION OF PENETRATION

The following equations and figure were used to calculate the yield stress as a function of the depth of penetration of the ASTM D 217 Penetrometer cone and two other lighter weight cones made of plastic and aluminum but conforming to the same dimensions as the standard cone. A correction for buoyancy was made using .0008 grams/cubic millimeter for the density of the gel.



DIMENSIONS IN MILLIMETERS

$$A_{TIP} = (\pi)(4.191)\sqrt{(4.191)^2 + (15.7)^2}$$

$$= 213.90 \text{ MM}^2$$

$$V_{TIP} = (1.047)(4.191)^2(15.7)$$

$$= 288.2 \text{ MM}^3$$

$$A_{CONE} = (\pi)(h-10.8)\sqrt{(h-10.8)^2 + (h-10.8)^2} - (\pi)(\sqrt{2})(4.191)^2$$

$$= (\pi)(\sqrt{2})\left[(h-10.8)^2 - 17.57\right]$$

$$V_{CONE} = 1.047\left[(h-10.8)^3 - 73.64\right]$$

$$A_T = A_{CONE} + A_{TIP} = (\pi)(\sqrt{2})\left[(h-10.8)^2 - 17.57\right] + 213.9$$

$$V_T = V_{CONE} + V_{TIP} = (1.047)\left[(h-10.8)^3 - 73.64\right] + 288.2$$

$$\text{BUOYANT FORCE} = J = (V_T)(\rho)$$

$$\rho = .0008 \text{ GRAMS/(MILLIMETER)}^3$$

$$\text{YIELD STRESS} = YS = \frac{\text{APPARENT CONE WEIGHT (DYNES)}}{\text{WETTED AREA (CENTIMETERS)}}$$

$$= \frac{(\text{ACTUAL CONE WEIGHT} - \text{BUOYANT FORCE})(980.67)(100)}{(A_T)}$$

$$= \frac{(98067)(C_W - .0008\ V_T)}{(A_T)}$$

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P	h = P × 10^{-1}	E = h − 10.8	E^2	E^3	F = E^2 − 17.57	G = $\pi\sqrt{2}$ F	AT = G + 213.9	H = E^3 − 73.64	I = 1.047 H
150	15.0	4.2	17.64	74.088	.07	.311	214.21	.488	.469
175	17.5	6.7	44.89	300.8	27.32	121.3	335.2	227	237.8
200	20.0	9.2	84.64	778.7	67.07	298.1	512	705	738.2
225	22.5	11.7	136.89	1601.6	119.32	530.1	744	1528	593 8
250	25.0	14.2	201.64	2863.3	184.07	817.8	1031.7	2790	2920.8
275	27.5	16.7	278.89	4567.	261.32	1161	1374.9	4584	4799.3
300	30.0	19.2	368.64	7078.	351.07	1560	1773.9	7004	73334
325	32.5	21.7	470.89	10218.	453.32	2015	2228.9	10145	10621.5
350	35.0	24.2	585.64	14172.	568.07	2525	2738.9	14099	147615
375	37.5	26.7	712.89	19034.	695.32	3091	3304.9	18961	19851.7
400	40.0	29.2	852.64	24897.	835.07	3710	3923.9	24823	25990.2
425	42.5	31.7	1004.89	31855.	987.32	4389	4602.9	31781	33275.1
450	45.0	34.2	1169.64	40002.	1152.07	5120	5333.9	39928	41804.7

Calc	BURK	6/1/67	REVISED	DATE	CALCULATIONS OF YIELD STRESS AS A FUNCTION OF PENETRATION	D6-15230
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DATA

$A_T =$ $G + 213.9$	$H =$ $E^3 - 73.64$	$I =$ $1.047\ H$	$V_T =$ $I + 288.2$	$J =$ $.0008\ V_T$	$W_{T150} =$ $150 - J$	$W_{T62} =$ $62 - J$	$W_{T28} =$ $28 - J$	$K = \frac{98067}{A_T}$	$YS_{150} =$ KW_{T150}	$YS_{62} =$ KW_{T62}	$YS_{28} =$ KW_{T28}
214.21	.488	.469	288.669	.23	149.77	61.77	27.77	457.7	68500	28260	12700
335.2	227	237.8	526.0	.42	149.58	61.58	27.58	292.8	43770	18020	8070
512	705	738.2	1026.4	.82	149.18	61.18	27.18	191.7	28600	11730	5210
744	1528	1599.8	1888.0	1.51	148.49	60.49	26.49	131.8	19570	7973	3491
1031.7	2790	2920.8	3209.0	2.57	147.43	59.43	25.43	95.0	14000	5644	2417
1374.9	4584	4799.3	5087.5	4.07	145.93	57.93	23.93	71.4	10410	4180	1708
1773.9	7004	7333.4	7621.6	6.1	143.9	55.9	21.9	55.3	7955	3092	1212
2228.9	10145	10621.5	10909.7	8.73	141.27	53.27	19.27	44.05	6223	2347	848.5
2738.9	14099	14761.5	15049.7	12.04	137.96	49.96	15.96	35.82	4941	1790	571.8
3304.9	18961	19851.7	20139.9	16.11	133.89	45.89	11.89	29.7	3972	1361	352.3
3923.9	24823	25990.2	26278.4	21.02	128.98	40.98	6.98	25.	3221	1025	174.4
4602.9	31781	33275.1	33563.3	26.85	123.15	35.15	1.15	21.32	2625	749	24.50
5333.9	39928	41804.7	42092.9	33.67	116.33	28.33	——	18.4	2140	521	——

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DATA SHEET

APPENDIX B

Coordination Sheet 727-FV-12, "Laboratory Vibration Test of Gelled Fuel"

AD 1546 D

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COORDINATION SHEET

TO B. C. Heinline

NO. 727-FV-12

C.C. W. J. Burk
A. J. Kamm
A. C. Larsen

ITEM NO.

DATE 1-19-67

MODEL 727

GROUP INDEX LOADS AND DYNAMICS UNIT

SUBJECT Laboratory Vibration Test of Gelled Fuel

REFERENCES: (a) Memo 6-7727-17 from B. C. Heinline to A. C. Larsen

(b) T6-2109, "Ground Vibration Test of the Model 727 Airplane"

Data on the low frequency vibration modes of Boeing subsonic jet transport wings has been requested for application in the laboratory vibration test of gelled fuel. The following is based on measurements on the model 727 airplane.

Vibration data recorded at wing station 770 during the 727 flight loads survey was reduced by computer analysis to a response envelope in terms of acceleration power spectral density. The portion of this envelope from .9 - 10 cps was converted to displacement power spectral density and plotted in Figure 1. As indicated the principal mode occurs at 3.0 cps. Contributions of other modes to total wing vibratory displacement is relatively small. The rms displacement response between .9 and 10 cps was computed to be 1.80 inches double amplitude.

Assuming a normal distribution, the probability that any given response amplitude, within the frequency range of the envelope, will exceed the rms response of the envelope is .60, i.e., the rms response will be exceeded 60% of the time. Similarly, two times the rms response will be exceeded 24% of the time, and three times the rms response will be exceeded only 1% of the time.

The above results from flight measurements were correlated with mode shapes determined in the ground vibration test (Reference b). The 3.2 cps mode shape is shown in Figure 2. A slightly higher frequency was measured during the ground test because there was no fuel in the wing. As indicated the maximum displacements occurred at the extreme outboard tank end, WS 760.5, with a node line occurring about WS 530.

To apply the above data to a laboratory test in which the vibrator is capable of producing a sinusoidal input of constant frequency, the following procedure is recommended:

72[illegible]-12
P[illegible] -2-
1-1[illegible]-67

1. The test set-up should provide a rotational vibration input with a [illegible] of not more than 250 in.

2. The input frequency should be 3 cps.

3. To insure a [illegible] test the input should be applied at each of the following displacement levels along the arc defined by (1) above.

   (a) 1.[illegible] in. double amplitude

   (b) 3.[illegible] in. double amplitude

   (c) 5.[illegible] in. double amplitude

4. Duration of testing at each input level should be adequate to insure that the gelled fuel has reached a stabilized condition under the effects of vibration.

D. L. Sevrist
D. L. Setrist

J. A. Skoog
J. A. Skoog

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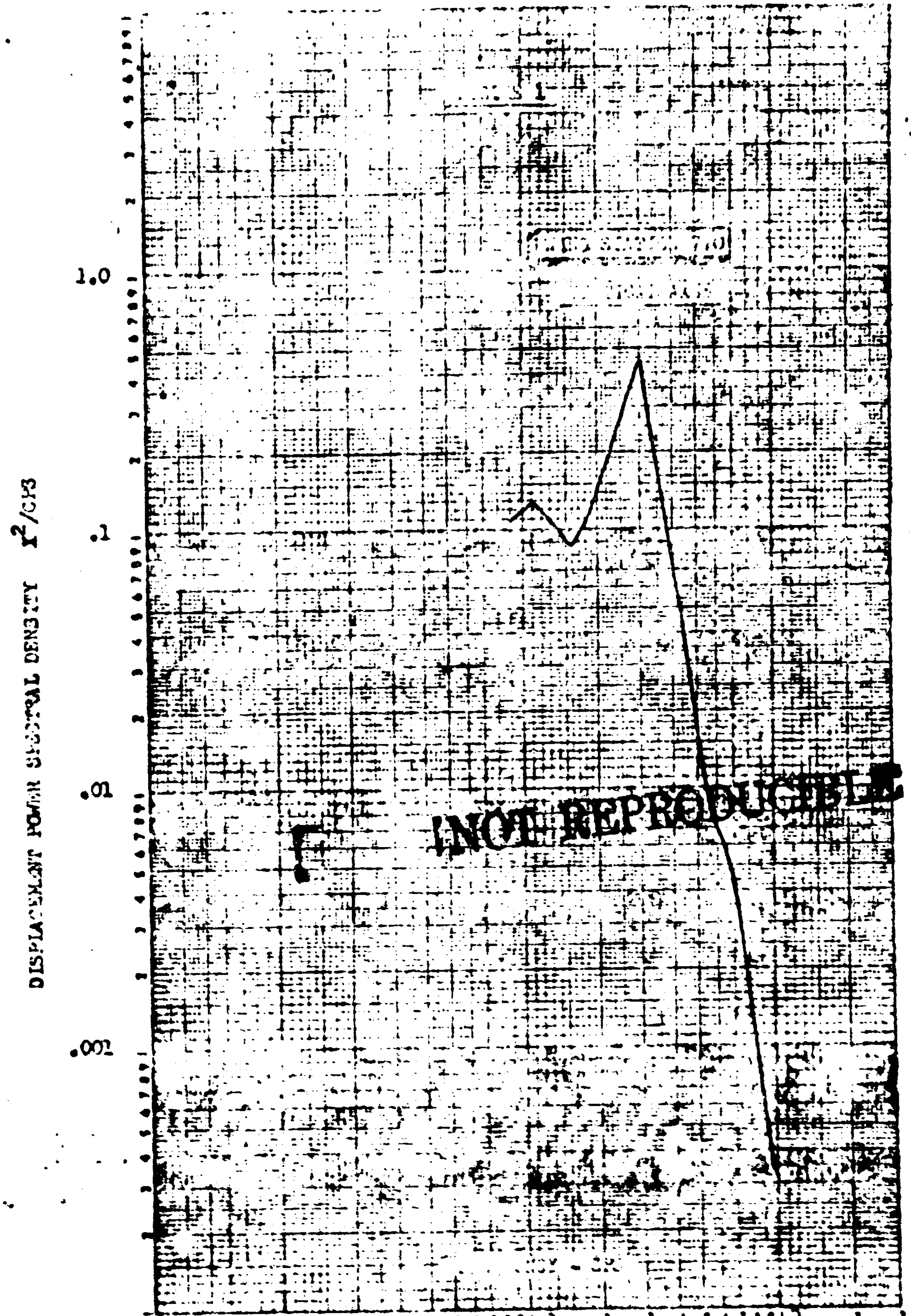

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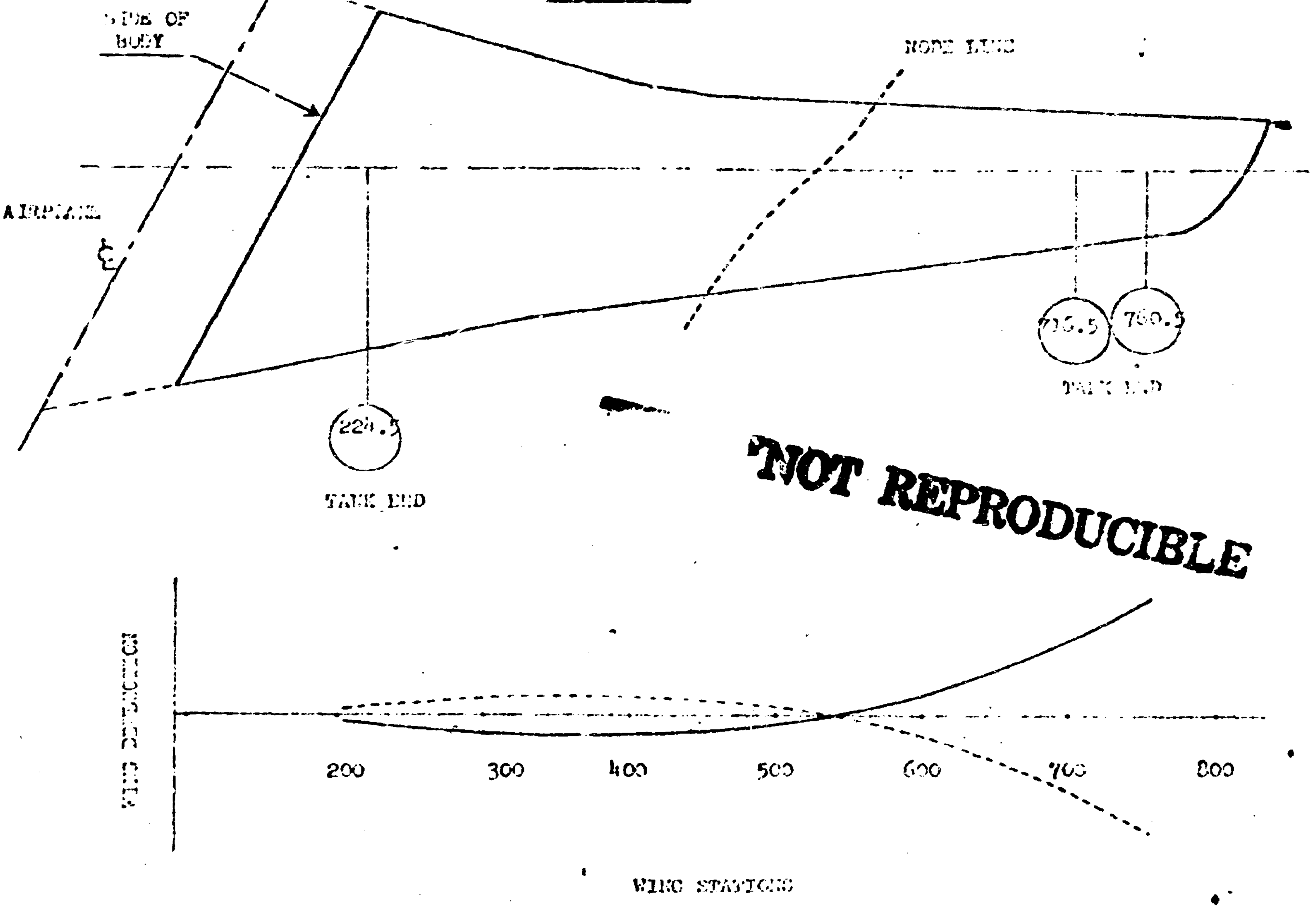
FIGURE 2



3.2 cps

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